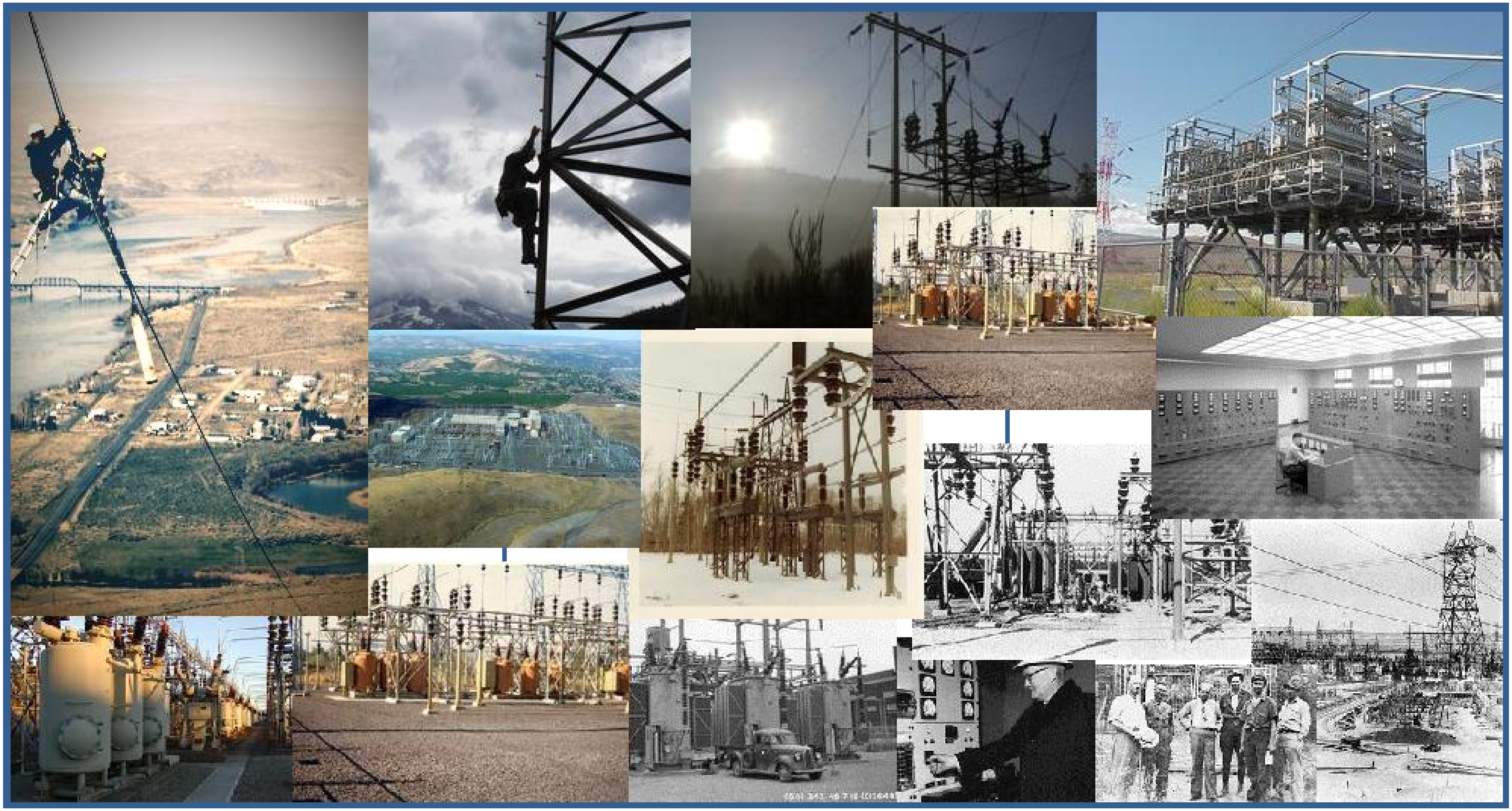

BPA 75 YEARS 1937–2012 SERVING THE NORTHWEST

FEBRUARY 2013

TRANSMISSION TECHNOLOGY ROADMAP

Bonneville Power Administration

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(* new roadmaps)

Introduction

Throughout its history, the Bonneville Power Administration (BPA) has been successful in responding to political, business, environmental and technological changes and demands. BPA has earned regional, national and international recognition as an innovative leader in technology breakthroughs and achievements that have saved electricity consumers in its territory millions of dollars. BPA has contributed greatly to the overall development of, and incremental improvements to the high-voltage power system in the Pacific Northwest, energy efficiency programs that support regional and national goals, non-wire solutions and environmental technologies.

Technology roadmaps are created to support research and development (R&D) plans that meet the strategic goals of industries and organizations with research needs. BPA's technology roadmaps are essentially a snapshot of current perspectives to inform a research agenda that will help BPA adapt to a new environment in which technology, regulation, generation resources, customer demands and power flows are changing dramatically.

The first edition of the Transmission Technology Roadmap was published in 2006 and identified 20 technologies that addressed business challenges facing BPA. In 2010, the Transmission Roadmap was revised in the current format and included ten technology areas in six categories. The 2012 version has two additional categories and seven new technology area roadmaps.

The technology roadmaps provide clarity on:

1. Key business challenges (environmental/global, market, policy and regulatory, and technology innovation) affecting the Federal Columbia River Power System (FCRPS);
2. Operational challenges facing BPA organizations that are created by the identified business challenges;
3. Technological needs that would help BPA manage the challenges;
4. Capability Gaps that the needs indicate we may want to acquire;
5. Technologies that may contribute to those capabilities; and
6. Gaps in existing R&D programs designed to address identified technology needs.

Business challenges were initially identified from four documents: BPA's Strategic Priorities, Transmission Services Key Agency Targets, the 2006 Transmission Technology Roadmap, and the 2010 Transmission Technology Roadmap. These were revised and confirmed during the roadmapping workshops and interviews to key stakeholders. Operational challenges, technical needs, and required capability corresponding to the business challenges are enlightened throughout workshop, group meetings and interview. Subject matter experts outside BPA verified required capabilities and related technologies.

The Transmission Technology Roadmap specifically addresses challenges facing BPA's high voltage transmission system and its interactions with generation sources and the distribution systems of its customers. The challenges are grouped in the following major areas:

A. Transmission Planning Operational Challenges

- I. Power System Modeling
- II. Transmission Operations
- III. Power Grid Optimization
- IV. Transmission Scheduling
- V. Workforce Enhancement

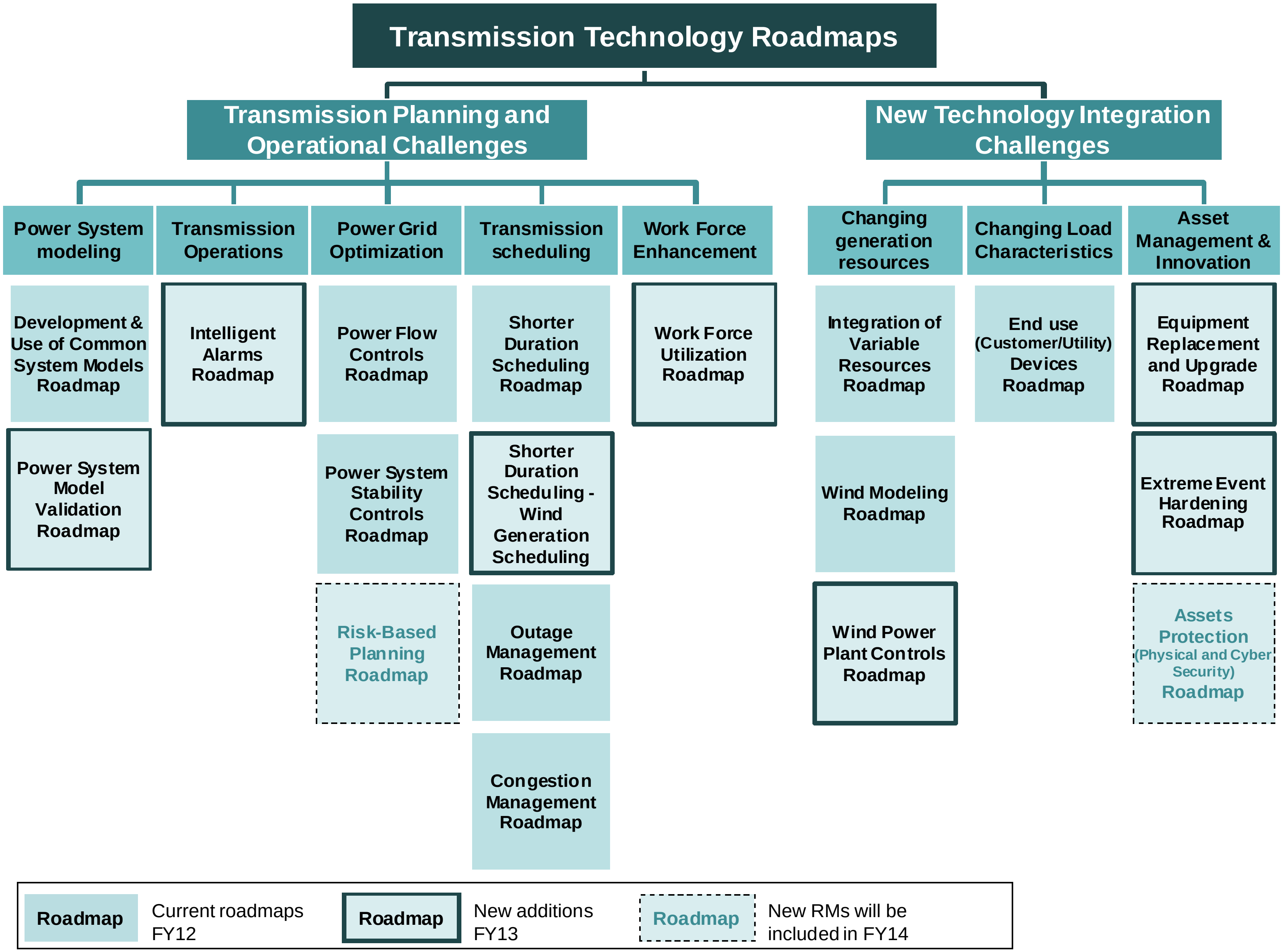
B. New Technology Integration Challenges

- VI. Changing Generation Resources
- VII. Changing Load Characteristics
- VIII. Assets Management & Innovation

The following roadmap document provides definitions of roadmap components such as layers and their relationships toward research gaps. The total 17 transmission technology roadmaps are grouped by 8 challenge areas defined above, and their highlights are provided. Each roadmap consists of three sections; summary of major challenges and needs, roadmap illustration including detail contexts and relationships, and short descriptions of internal and external research projects related to the challenges.

The objective of BPA's Technology Innovation program is to provide the impetus to transform R&D into best practice applications. The roadmapping process identifies critical technologies that have the potential to improve system reliability, lower rates, advance environmental stewardship and provide regional accountability.

Transmission Technology Roadmap Areas



Key Challenge Areas

A. Transmission Planning and Operational Challenges

I. Power System Modeling

- **Development and use of common system models –** The system models from power generation through transmission planning to transmission scheduling and operations are not consistent. Another challenge is due to the Insufficient Power System Models. Current models are insufficient to simulate power flow scenarios with multiple contingencies that include intermittent and variable generation.

- **Power system model validation –** Model validation is an essential procedure for maintaining system security and reliability. Major changes include BPA's current capability to comply with FERC/NERC/WECC standards/requirements and promote adequate, efficient, and reliable regional transmission in a cost effective manner.

II. Transmission Operations

- **Intelligent alarms –** With hundreds of different processes running at once, operators can be hard pushed to keep up with alarms, even under normal conditions. Without careful management, alarms can be ignored by even the most diligent of operators.

III. Power Grid Optimization

- **Power flow controls –** BPA desires to increase capacity of the transmission system without extensive capital investment. The ability to explicitly control power flow and voltage stability is required.

- **Power system stability controls –** As synchrophasors are being deployed to the region, utilization of the data are challenged. Synchrophasors can leverage wide area and response based controls, and increase reliability and throughput. Protection of load voltage and transformer protection against GIC are also challenging areas. Human factor – Human performance and system complexity must be evaluated to minimize reliability risks.

IV. Transmission Scheduling

- **Shorter duration scheduling –** Wind generation scheduling becomes a challenge to BPA due to its intermittency and lack of forecasting capability for scheduling. There are four major challenges in short duration scheduling of transmission scheduling: forecasting transmission flows in near-term, sub-hour scheduling, integration of ancillary energy markets, difficulty in accommodating variability in demand and supply, and potential formation of region-wide energy imbalance market.

- **Outage management –** Increased pressure to replace equipment 'Hot' (without an outage), and Increased difficulty to take outages on power system equipment and lines because of insufficient capacity and increasing demand.

- **Congestion management –** BPA has difficulty in identifying drivers for congestion and determining congestion costs for expansion planning purposes given the increases in wind generation, changes in system operations (SOL, EIM) and new storage and DR resources.

V. Work Force Enhancement

- **Work-force utilization –** Human error in operations of system protection equipments cause transmission system outages. Need to improve work efficiency and maximize workforce through workforce management system for scheduling and knowledge management.

B. New Technology Integration Challenges

VI. Changing Generation Resources

- **Integration of variable resources –** As large amounts of variable generation such as wind are added to the energy mix in the Pacific Northwest, increasing amounts of flexible dispatchable resources are required to integrate them.

- **Wind modeling –** The current models of transmission system planning do not effectively incorporate impact of wind generations. Improved modeling of wind resources on the transmission system is needed to provide accurate, real-time information for energy markets, scheduling, reserves management and voltage support.

- **Wind power plant controls –** Wind generation facilities should be able to exert effective control capability in response to grid requirements such as primary speed-power control, primary voltage control, secondary voltage control and reactive power management.

VII. Changing Load Characteristics

- **End use devices –** The changing characteristic of end-use devices is a critical business challenge for the BPA transmission system. Grid friendly devices and better load management tools that enhance the transmission system operation.

VIII. Asset Management and Innovation

- **Equipment replacement and upgrades –** BPA's aging infrastructure requires equipment replacement & upgrade projects which are a large investment and present BPA several business challenges. New standards (ISC 6180) are driving major changes in equipments. New sensors can provide better system and equipment performance.

- **Extreme event hardening –** The agency's critical transmission assets, services and functions can be disrupted because of extreme events resulting in regional economic hardship, threats to regional health and safety, and significant restoration costs.

Proposed Updates for Next Version

Additional Technology Roadmaps

A. Transmission Planning Operational Challenges

Power Grid Optimization

- Risk-Based Planning

B. New Technology Integration Challenges

Asset Management and Innovation

- Assets Protection (Physical and Cyber Security)

Definitions of the Roadmap Layers

Roadmap Technology Area | **Roadmap Title** | BPA Transmission Technology Roadmap

Time

- **Business Challenges (BC)** — **BC:** Business Challenges describe factors, risks, issues, or problems threatening BPA's Transmission organization's ability to achieve Transmission Services strategic goals. The specific challenges in scope for this Roadmap are those where a technical solution potentially provides resolution.
- **Operational Challenges (OC)** — **OC:** Operational Challenges describe the current or future manifestation of the Business Challenge and the tangible impact on the ability of Transmission Services core functions to achieve expected results.
- **Operational & Technical Needs (ND)** — **ND:** Operational and Technical Needs corresponding to a certain operational challenge describe potential technical instances or symptoms associated with the challenge.
- **Required Capabilities (RC)** — **RC:** Required capabilities, linked to an Operational or Technical Need, describe characteristics, metrics or target features of the technical subject to resolve the associated challenges. These will provide the quantification needed to develop the gap analysis and the measurement of its closure.
- **Technologies (T)** — **T:** Technologies are specific technical approaches satisfying the technical features described by the Required Capabilities. The technologies could be currently available, under development, or a new technical approach requiring research programs.
- **R&D Programs (RD)** — **RD:** R&D Programs are collections of R&D projects related to a specific technology. The R&D program may include current R&D projects or new R&D projects that should be initiated.

Legend: Business Challenge | Operational Challenge | Operational & Technical Need | Required Capability | Technologies | Existing R&D Programs | Non-Existing R&D Programs (Gaps)

I. Power System Modeling

Development and Use of Common System Models Roadmap

Business and Technology Challenges

A critical challenge for BPA's transmission modeling systems is the inconsistency of system models from power generation through transmission planning to transmission scheduling and operations. Currently, power system analyses use multiple models and data bases that are not integrated. A common architecture is needed that can communicate across planning, design and operation to perform power system modeling that increases transmission capacity and control of power flow. It should include improved and expanded base case power flow capabilities with automation tools that move from snap shots to real time. It should include accurate, quality WECC base case data with proper labels.

This impacts several areas creating the following operational challenges:

- Identifying New System Constraints Following Dispatch Changes
  - Current models do not identify new system constraints following dispatch changes. They do not indicate which plants to turn off and which plants must stay on to provide ancillary services.
  - Planning studies with perfect foresight may not match actual results when there is forecast error.
  - We have difficulty in quantifying the risk of increased reliance on RAS, and redispatch.
  - Models may be too optimized for one set of assumptions precluding their use for broader applications.
  - We don't have good planning models for all possible operating conditions. Currently, focus is on winter peak and summer peak.
- Forecasting Congestion
  - Difficulty in forecasting congestion and congestion costs for expansion planning purposes
  - Given ramp up in wind changes in system operations (Operational Transfer Capacity, Energy Imbalance Market) new storage and Demand Response resources
- Model Consistency: Need more consistency of assumptions between planning & operations or more awareness of inconsistency. Planning studies do not have perfect 'Foresight'.

Another business challenge is coming from a fact that current models do not simulate power flow scenarios with multiple contingencies that include intermittent and variable generation. This causes following operational challenges.

- Analysis / Data Availability: Real-time interoperable monitoring and measuring hardware integrated with interoperable software is needed to translate and convert the data collected into meaningful information to support operating decisions and to get increasingly complex issues resolved faster.
- Adapting to a Changing Power System: Effective integration of new generation and changing load patterns requires changes to scenario planning that accommodates a variety of resources such as renewable and distributed energy, demand response and non-wire solutions.

Exploration and prototyping is needed for new automatic control schemes that complement and enhance the control capabilities of human operators.

The operational and technical needs to respond to those challenges include:

- Increase Planning Scenarios: Need new system planning tools to develop a better planning system for more broad (encompassing) data.
- Better State Estimator Models: Need better state estimator models. Validate Wind Models
- Baseline Understanding of the System (Power System Performance)
- Need for baseline performance values for an evolving system with a diversity of generation including: Oscillation baseline; Frequency response baseline; and Phase angle baseline
- Reliable source for topology/impedance model realizing elements such as load and generation models

The required capabilities to satisfy the needs are:

- Power Plant Model Validation: Need baseline performance for changing generation, based on RT SE topology/impedances. Better accuracy of breakers/bus and PMUs for load and generation parameter ID.
- Scenario Analysis: BPA needs to run a wide range of study scenarios and process the results in a useful amount of time.
- Common System Model: BPA needs common model data structures & parameters with tools to maintain the database and change the management process. The database will essentially be comprised of three key components; operational breaker/node model database; planned future system additions; and dynamic database. The model will have an interface with the EMS SCADA database for real time measurements with an integrated network application environment that includes a closed loop update.

R&D Gaps

Business and Technological Challenges which are not addressed by existing R&D programs:

1. Forecasting Congestion
2. Modeling HILF (high impact low frequency), geomagnetic disturbance / geomagnetically induced currency (GMD/GIC)
3. Transformer models to evaluate the Impact of GIC for the generation of harmonics increased VAR consumption and thermal stress on transformers

Business and Technological Challenges which are covered partially by existing R&D programs but still require further research and development:

1. Model Consistency
2. Analysis / Data Availability
3. Adapting to a Changing Power System
   - There are a number of Locational Marginal Pricing (LMP) methodologies currently practiced by all the Independent System Operators (ISO), Regional Transmission Organizations (RTO) and Energy Imbalance Market (EIM) operators. What is different between the current practices/methodologies for LMP and those for existing R&D projects?

Business and Technological Challenges which are covered by commercialized technologies and products, however demonstration or confirmation studies may be required.

1. Insufficiency of power system models: Current BPA models do not sufficiently simulate power flow scenarios with multiple contingencies that include intermittent and variable generation.
   - Almost all Energy Management Software (EMS) vendors already have state estimators that can do the above. The need is to verify if they are sufficient for BPA purposes.
2. Need to identify new system constraints following dispatch changes.

I. Power System Modeling

I-1. Development and Use of Common System Models Technology Roadmap

BPA Transmission Technology Roadmap

Time: 2012 – 2015

Business Challenges (BC)

BC1 Consistent System Models from Planning through Operations
Planning and Operations rely on power system analyses requiring increased use of modeling that currently uses multiple models and data bases. A lack of an integrated database structure where real time information can be stored and retrieved makes it difficult for the systems engineer to validate study results. We have a fragmented model system due to history. We now have an opportunity to increase productivity, reduce inconsistency, and enhance timeliness and accuracy because of advances in algorithms, computing horsepower, data fidelity and resolution (due to syncrophasors) etc.
BPA stores real time data now in SHIP and PI. The labels don't match WECC base cases.

BC2 The Evolving Power System
Current models are insufficient to comprehend the power system as it incorporates new types of variable generation and load.

Operational Challenges (OC)

OC1 Identifying New System Constraints Following Dispatch Changes
BPA has difficulty in identifying new system constraints following dispatch changes. Which plants will turn off, - which plants have to stay on for ancillary services (balancing, voltage support, etc.) Planning studies with perfect foresight may not match actual results when there is forecast error. We have difficulty in quantifying the risk of increased reliance on RAS, and redispatch. Models may be too optimized for one set of assumptions precluding their use for broader applications. We don't have good planning models for all possible operating conditions. Currently, focus is on winter peak and summer peak.

OC2 Forecasting Congestion
Difficulty forecasting congestion and congestion costs: 1) for expansion planning purposes, 2) Given ramp up in wind changes in system operations (Operational Transfer Capacity, Energy Imbalance Market) new storage and Demand Response resources,

OC3 Model Consistency
Need more consistency of assumptions between planning & operations. Or more awareness of inconsistency. Planning studies do not have perfect 'Foresight'. (S)

OC4 Analysis / Data Availability: Tools, modeling, and speed personnel. Need to get more complex issues resolved faster.

OC5 Identify Problems in the operating system: New ways of operating the system; new patterns of operation mean new problems we don't know about. (S)

Operational & Technical Needs (ND)

ND1 Increase Planning Scenarios
Need new system planning tools to develop a better planning system for more broad (encompassing) data.

ND2 Better State Estimator Models: Need better state estimator models. Validate Wind Models (TIP 52)

ND3 Baseline Understanding of the System (Power System Performance)
Need for baseline performance values for an evolving system with a diversity of generation including: Oscillation baseline; Frequency response baseline; and Phase angle baseline

ND4 Reliable source for topology/impedance model. Realize elements (load and generation models)

Required Capabilities (RC)

RC1 Power Plant Model Validation
Need baseline performance for changing generation, based on RT SE topology/impedances. Better accuracy of breakers/bus and PMUs for load and generation parameter ID.

RC2 Scenario Analysis
BPA needs to run a wide range of study scenarios and process the results in a useful amount of time.

RC3 Common System Model Needs
BPA needs common model & parameters and tools to maintain database and change management process. The database will essentially be comprised of three key components; Operational breaker/node model database, Planned future system additions, dynamic database. The model will have an interface with the EMS SCADA database for real time measurements with an integrated network application environment that includes a closed loop update.

Technologies (T)

T1 Consistent Assumptions
PBA Power Policy Analysis group is working on consistent assumptions for various models & robust state estimator.

T2 Model Accuracy
The accuracy of the existing WSM models at the WECC RC, BPA State Estimator and SCADA system need to be tested.

T3 Modeling Tools
Model exchange, base case building automation, power flow solution techniques, data validation and quality checking.

R&D Programs (RD)

- BPA TIP 46 Operations real time study process improvement (TRL-8)
- BPA TIP 250 Control room and advanced PMU visualizations using PowerWorld retriever (TIP-8)
- EPRI: IntelliGrid - Program 161 - P161.003 Common Information Model and Information Integration for Transmission Applications (2011)
- PSERC: Quantifying Benefits of Demand Response and Look-ahead Dispatch in Support of Variable Resources (M-26)
- BPA TIP 251: Implementation of a full-topology, three-phase, robust, and generalized state estimator (TIP-7)
- BPA TIP 240: SHORT TERM FCRPS MODELING DEVELOPMENT
- PSERC: The Smart Grid Needs: Model and Data Interoperability and Unified Generalized State Estimator (S-39)
- PSERC: The Development and Application of a Distribution Class LMP Index (M-25)
- PSERC: Seamless Power System Analytics (S-46G)
- PSERC: Next Generation On-Line Dynamic Security Assessment (S-38)
- BPA TIP 25C - Geomagnetic Disturbance (TRL-5)
- BPA TIP 290 - Modeling high impact low frequency geomagnetic disturbances using magnetic field data from solar-orbiting spacecraft (TRL-6)
- BPA TIP 264 - Modeling Geomagnetically Induced Current for Evaluation and Mitigation (TRL-8)
- BPA TIP 279 - Implementation of a Full-Topology, Robust, and Generalized State Estimator (TRL-7)

Business Challenge | Operational Challenge | Operational & Technical Need | Required Capability | Technologies | Existing R&D Programs | Non-Existing R&D Programs (Gaps)

Related Internal and External Projects

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Inconsistent System Models from Planning through Operations, Models may be too optimized for one set of assumptions precluding their use for broader applications	PSERC PL: Mladen Kezunovic (Texas A&M University)	**NO**	**The Smart Grid Needs: Model and Data Interoperability and Unified Generalized State Estimator (S-39)** Future Smart Grid applications such as Unified Generalized State Estimation, Intelligent Alarm Processing, and Optimized Fault Location, can benefit from the smart grid integration across data and models but the problem of data and model interoperability hinders the implementation. As an example, two difficult and interrelated problems in state estimation, ability to detect topology errors, and implementation complexity due to the two-model (node/breaker and bus/branch) architecture, will be much easier to solve if data and model interoperability are resolved. This project will identify the interoperability issues and will illustrate novel ways of their resolution in the future so that both legacy solutions, as well as future smart grid applications can utilize the same data and models but use them in a manner consistent with the application requirements and aims. **REVIEW: A number of collaborative efforts for model interoperability testing has been done at EPRI level.**
Inconsistent System Models from Planning through Operations, Models may be too optimized for one set of assumptions precluding their use for broader applications	EPRI	**NO**	**IntelliGrid - Program 161 - P161.003 Common Information Model and Information Integration for Transmission Applications (2011)** Robust and highly integrated communications and distributed computing infrastructures will be needed to create a smart grid. These infrastructures need to be interoperable across vendor equipment and throughout the enterprise. Achieving the necessary level of interoperability requires the development and industry adoption of a tightly coupled suite of standards. The Common Information Model (CIM) provides a common language for integrating applications across the enterprise and is a foundation standard for smart grids. IEC 61850, Distributed Network Protocol (DNP), and the Internet Protocol (IP) also are key standards. Significant work has been done on these standards, but a substantial amount of work is needed. This project develops requirements and use cases for advanced transmission operations. These requirements serve as the basis for data and device models for emerging standards as well as for contributions to standards activities within key industry organizations such as IEC, IEEE, NIST and others.
Requires changes to scenario planning that accommodates a variety of resources such as renewable and distributed energy, demand response and non-wire solutions	PSERC PL: Le Xie (Texas A&M University)	**NO**	**Quantifying Benefits of Demand Response and Look-ahead Dispatch in Support of Variable Resources (M-26)** The objective of this project is to conduct a first-of-its-kind empirical study on the benefits of combining look-ahead dynamic dispatch with price responsive demands for integration of variable energy resources. Based on substation level demand response data and site-specific wind generation data from ERCOT, this project will develop algorithms and a case study to quantify (1) the price elasticity of demand for typical users, and (2) the economic benefit of look-ahead dispatch with price responsive loads. To our knowledge, this is the first study to estimate demand response at the customer level for a U.S. regional system operator. Moreover, we will combine the look-ahead dispatch with the price responsive demand to quantify the system-wide benefits.

<table>
<tr><th>BPA Challenge</th><th>Lead Research Organization</th><th>BPA Sponsoring</th><th>Project Title & Project Description</th></tr>
<tr><td>Inconsistent System Models from Planning through Operations. Current models are insufficient to simulate power flow scenarios with multiple contingencies that include intermittent and variable generation.</td><td>EPRI

[Satisfies the challenge 50%]</td><td>**NO**</td><td>**1. Existing Commercial Solutions**
CIM, proposed in the late 90's
- A formal method to define power system data using formal database models.
- EMS vendors have created converters to the CIM model from their proprietary models, but little development of CIM-native applications have occurred in the industry
- CIM has been only partially adopted. There are ongoing users groups for CIM interoperability and development.
- Interoperability is currently limited to various vendors solving small power flow cases
- A problem with CIM is that is very verbose, and the equivalent of planning cases requires Gbytes
- A second problem is that is defined at the abstract level.
2. Ongoing Research
CIM, EPRI is investigating the possibility to propose a canonical data format such as CIM. However, changes are needed to:
- Resolve the issue of large size of power flow cases
- CIM is an abstract model as opposed to a physical model. It is not suited for compliance because its implementation is left to the developer.
3. Research Needs
A common, flexible data format for power systems is needed in the industry. CIM could be a good starting point, but clear model adoption roadmap, compliance mechanisms, and a vast array of applications supported must be set upfront. Organizational and cooperation mechanisms must be in place so adoption of the model does not take decades.

REVIEW: CIM supposes to be a common format and power system models can be exchanged at ease, but non of the EMS vendor CIM versions can be exchanged at this point, regardless of relentless industry efforts. This is questionable in terms of practicality!</td></tr>
<tr><td>Analysis and data availability, Adapting to a changing power system</td><td>PSERC PL:
Vijay Vittal Arizona (State University)</td><td>**NO**</td><td>**Next Generation On-Line Dynamic Security Assessment (S-38)**
This project addresses five elemental aspects of analysis for the enhanced performance of on-line dynamic security assessment. These five elemental components includes; a) A systematic process to determine the right-sized dynamic equivalent for the phenomenon to be analyzed, b) Employing risk based analysis to select multi-element contingencies, c) Increased processing efficiency in decision-tree training, d) Using efficient trajectory sensitivity methods to evaluate stability for changing system conditions, and e) Efficient determination of the appropriate level of preventive and/or corrective control action to steer the system away from the boundary of insecurity.

REVIEW: This project is on its own merit and not related to the Common Power System Model.</td></tr>
</table>

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Requires changes to scenario planning that accommodates a variety of resources such as renewable and distributed energy, demand response and non-wire solutions	PSERC PL: Gerald T. Heydt (Arizona State University)	**NO**	**The Development and Application of a Distribution Class LMP Index (M-25)** This project focuses on the development and application of a distribution engineering analog of Locational Marginal Prices (LMPs). It is proposed to develop and apply a distribution LMP (D-LMP), which is used for energy and power flow management in networked distribution systems as well as pricing. The D-LMP will be designed to encourage the implementation of renewable resources in distribution systems in a cost effective way. The D-LMP signal may be used for control strategies such as management of distributed energy storage operation.
Inconsistent System Models from Planning through Operations, Models may be too optimized for one set of assumptions precluding their use for broader applications	PSERC PL: James McCalley (Iowa State University)	**NO**	**Seamless Power System Analytics (S-46G)** The current approach to power system analysis has developed over the last 3-4 decades in a piecemeal approach where the various applications run separately using their own system models and formats. Although these tools have improved, the programs are still built upon core technology and software architectures from decades ago, each developed for its own unique purpose rather than an integrated approach that builds upon state-of-the-art algorithms, hardware, and modern day methods for data management across a shared environment. These limitations need to be overcome by modern analytical tools that can support modernization of the electricity industry. This project will identify design requirements to transition to a new systems analysis platform that encapsulates a comprehensive power system model with seamless analytics. Design requirements are organized as: (a) types of organizations and analysis needs of each; (b) computing applications associated with each analysis need; (c) basic functions comprising each computing application; (d) algorithm/hardware combinations associated with each function; (e) software architecture designs to facilitate seamless and computationally efficient power system analysis. **REVIEW: Too general and broad base. Need to be more specific to power system applications, software and database.**
Inconsistent System Models from Planning through Operations, Models may be too optimized for one set of assumptions precluding their use for broader applications	PSERC PL: Mladen Kezunovic (Texas A&M University)	**NO**	**The Smart Grid Needs: Model and Data Interoperability and Unified Generalized State Estimator (S-39)** Future Smart Grid applications such as Unified Generalized State Estimation, Intelligent Alarm Processing, and Optimized Fault Location, can benefit from the smart grid integration across data and models but the problem of data and model interoperability hinders the implementation. As an example, two difficult and interrelated problems in state estimation, ability to detect topology errors, and implementation complexity due to the two-model (node/breaker and bus/branch) architecture, will be much easier to solve if data and model interoperability are resolved. This project will identify the interoperability issues and will illustrate novel ways of their resolution in the future so that both legacy solutions, as well as future smart grid applications can utilize the same data and models but use them in a manner consistent with the application requirements and aims.

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Inconsistent System Models from Planning through Operations, Models may be too optimized for one set of assumptions precluding their use for broader applications	EPRI	**NO**	**IntelliGrid - Program 161 - P161.003 Common Information Model and Information Integration for Transmission Applications (2011)** Robust and highly integrated communications and distributed computing infrastructures will be needed to create a smart grid. These infrastructures need to be interoperable across vendor equipment and throughout the enterprise. Achieving the necessary level of interoperability requires the development and industry adoption of a tightly coupled suite of standards. The Common Information Model (CIM) provides a common language for integrating applications across the enterprise and is a foundation standard for smart grids. IEC 61850, Distributed Network Protocol (DNP), and the Internet Protocol (IP) also are key standards. Significant work has been done on these standards, but a substantial amount of work is needed. This project develops requirements and use cases for advanced transmission operations. These requirements serve as the basis for data and device models for emerging standards as well as for contributions to standards activities within key industry organizations such as IEC, IEEE, NIST and others.
Requires changes to scenario planning that accommodates a variety of resources such as renewable and distributed energy, demand response and non-wire solutions	PSERC PL: Le Xie (Texas A&M University)	**NO**	**Quantifying Benefits of Demand Response and Look-ahead Dispatch in Support of Variable Resources (M-26)** The objective of this project is to conduct a first-of-its-kind empirical study on the benefits of combining look-ahead dynamic dispatch with price responsive demands for integration of variable energy resources. Based on substation level demand response data and site-specific wind generation data from ERCOT, this project will develop algorithms and a case study to quantify (1) the price elasticity of demand for typical users, and (2) the economic benefit of look-ahead dispatch with price responsive loads. To our knowledge, this is the first study to estimate demand response at the customer level for a U.S. regional system operator. Moreover, we will combine the look-ahead dispatch with the price responsive demand to quantify the system-wide benefits..
Inconsistent System Models from Planning through Operations. Current models are insufficient to simulate power flow scenarios with multiple contingencies that include intermittent and variable generation.	Georgia Institute of Technology PL: Dr. Santiago Grijalva **[Satisfies the challenge 30%]**	**NO**	**1. Ongoing Research** Ongoing research on the unified data model and framework with applications to generalized state estimation. - Further testing of performance of the unified framework for various applications including operations and planning compatibility at the N-k contingency analysis level **2. Research Needs** - Industry-wide utilization of the unified operations and planning framework .- Methods to test interoperability of unified models - Utility/ISO planning directly with node-breakers models - Implications of potential abandonment of bus/branch models - Widespread creation of WECC or Eastern Interconnection models at the node-breaker level **REVIEW: Others EPRI, WECC WSM, PowerWorld, etc. have done what stated in the proposal.**

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Insufficient Power System Models - Current models are insufficient to simulate power flow scenarios with multiple contingencies that include intermittent and variable generation	BPA PL: Thong Trinh **[Satisfies the challenge 80-100%]**	**YES**	**BPA EXP 16 Development of a Common Power System Model and Database** Increasing reliance on power system analyses for the operation and planning of the power system has led to modeling being elevated to a critical function for both planning and operations. Models are supporting a variety of enterprise functions, and better model exchanges are needed. Today, the need for model consolidation and sharing is on everyone's mind. The necessity for: better operating tools, increased transfer capability, accurate real-time load forecasts, validation of power system dynamics, and smart grid will all carry this trend further. This project proposes the development of a centralized database that includes closed loop update and maintenance processes, and integrated network applications. The database will essentially be comprised of three key components: Operational breaker/node model; Planned future system additions; Dynamic database. The model will have an interface with the EMS SCADA database for real time measurements with an integrated network application environment with closed loop. **REVIEW: This is a practical approach that deals with real practical needs.**
Inconsistent System Models from Planning through Operations. Current models are insufficient to simulate power flow scenarios with multiple contingencies that include intermittent and variable generation.	Siemens	**NO**	**1. Existing Commercial Solutions** Siemens has created a product capable of mapping models between their EMS system and their PSSE models. Effectively the model is a case converter from the EMS to centralized database to PSSE. However, because fundamentally the planning cases loses information of the switching devices, it is not possible to "go bacK" from the planning model to the operations model. System has been deployed successfully at various control centers, ERCTO, etc. **REVIEW: First sentence is not entirely truth. MOD (Model On Demand) still not capable of completely doing as stated. This is to solely benefit Siemen PSSE product.**
Inconsistent System Models from Planning through Operations. Current models are insufficient to simulate power flow scenarios with multiple contingencies that include intermittent and variable generation.	Texas A&M PL: Mladen Kezunovic **[Satisfies the challenge 5%]**	**NO**	**1. Ongoing Research** Ongoing research on data model compatibility between fault detection and operational models

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Modeling HILF (high impact low frequency), geomagnetic disturbance / geomagnetically induced currency (GMD/GIC)	EPRI	**YES**	**TIP 25C - Geomagnetic Disturbance** The initial objective will be to determine the state of knowledge of GMD. This will include a review of the available literature and interviews of industry experts to collect and validate industry data on the probability of extreme events and the extent to which storms can reasonably be anticipated. System models will be developed of representative regions of the North American grid in cooperation with North American Electric Reliability Corporation (NERC) staff. The models are designed to determine how the system and equipment respond to various storm scenarios or to evaluate candidate mitigation technologies. All results will be analyzed by a technical team comprised of NERC, utility, and EPRI staff.
Modeling HILF (high impact low frequency), geomagnetic disturbance / geomagnetically induced currency (GMD/GIC)	Queen's University at Kingston	**YES**	**TIP 290 - Modeling high impact low frequency geomagnetic disturbances using magnetic field data from solar-orbiting spacecraft** Although various government agencies (e.g. NOAA) provide short-term (hours to days) forecasts of space weather that can be used for more immediate management of power transmission, there is a need for longer-term space climate forecasts that can inform management and planning processes over an extended time horizon. The aim of this project is to develop a method to forecast and predict extreme solar events at long time horizons. This in turn will allow for the prediction of potentially harmful geomagnetic disturbances. Deliverables: ▪ Supporting data from Ulysses and ACE satellites, solar flare data and geomagnetic data. ▪ Forecast of flare probabilities as far into the future as reliable forecasts can be made (to be determined); quantification of forecast reliability. ▪ Description of the techniques used for analysis, including software to perform the analysis. ▪ Final report including potential follow-on projects. ▪ Copies of manuscripts submitted for publication in refereed journals.

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Inconsistent System Models from Planning through Operations. Current models are insufficient to simulate power flow scenarios with multiple contingencies that include intermittent and variable generation.	PowerWorld	**YES**	**TIP 264 - Modeling Geomagnetically Induced Current for Evaluation and Mitigation** PowerWorld has developed an innovative tool for analyzing the potential impact of geomagnetic disturbances (GMD), using our familiar power flow and transient stability platforms. PowerWorld Simulator GIC may be the most accessible tool in the world for power system planning and operations engineers to readily assess GMD risk posed to their systems. Power systems are vulnerable to time and spatial variations in dc ground voltages caused by GMD. Geomagnetically induced currents (GICs) flow through circuits formed by the earth, a grounded transformer, a high-voltage transmission line, and another grounded transformer at the far end of the transmission line. Deliverables: ▪ The first deliverable will be a completed GIC study of the BPA system. A report will be written on the GIC impact and mitigation strategies for BPA. ▪ The next deliverable will be software that incorporates the development of algorithms to determine optimal mitigation strategies. This will become part of the standard GIC tool in PowerWorld Simulator. ▪ The next deliverable will be a report on the testing and validation of GIC parameters for BPA's system. The results of these results will be integrated into the GIC study report. ▪ The final deliverable will be improved visualization of GIC flows in PowerWorld Simulator, which will become part of the standard visualization toolkit for the GIC tools in Simulator.
Better State Estimator Models	PowerWorld	**YES**	**TIP 279 - Implementation of a Full-Topology, Robust, and Generalized State Estimator** The goal of this project is to create a state estimator which overcomes this limitation by meeting two major objectives as follows: 1. Must include integrated topology error detection, 2. Must operate on a single power system model representing the full-topology Deliverables: ▪ A PowerWorld Simulator/Retriever version that includes an orthogonal factorization built on QR factorizations using givens rotations ▪ A PowerWorld Simulator/Retriever version that includes expanded state estimation algorithms to utilize full-topology Models ▪ A PowerWorld Simulator/Retriever version that includes full implementation of topology error detection in the full-topology framework ▪ A final report detailing the completed tasks and the updated software

Power System Model Validation Roadmap

Business and Technology Challenges

Model validation is an essential procedure for maintaining system security and reliability. The procedure may be viewed as a “top-down” approach to model verification; comparisons with measured data indicate the quality of the overall model.

Business challenges presented below illustrate the importance of system model validation.

- Compliance with FERC/NERC/WECC standards and initiatives
- Ability to promote adequate, efficient, and reliable regional transmission in a cost effective manner
- Long-term value of transmission assets
- Smart Grid distribution linkage, what is the link between bulk transmission system and the evolving distribution of the Smart Grid system

Operational and technical challenges consist of:

- Improving the quality of power system models especially wind power plant models
- Inadequate technical expertise of generation owners’ to conduct reliable model validation testing
- BPA’s abilities to comply NERC Standards (MOD 24 -27, PRC 19-24)
- Ability to continuously monitor generation plants against performance benchmarks
- New NERC operations requirements
- State Estimators based on insufficient power flow models

R&D Gaps

Business and Technological Challenges which are not addressed by existing R&D programs:

- None

Business and Technological Challenges which are covered partially by existing R&D programs but still require further research and development:

1. Advanced software tools
    - Software that can sort through large amounts (200TB) of PMU data and identify significant events per modeling
2. Unified modeling approach for both operations and planning which enables convergence of planning and operations
    - Methods and tools unify bus/branch and node/breaker models seamlessly What this unified modeling allows is to (directly) compare what planners and operators see without any model conversion, data mapping or manual scripting process.

Business and Technological Challenges which are covered by commercialized technologies and products, however demonstration or confirmation studies may be required:

- None

I-2. Power System Model Validation Technology Roadmap

Time | **NEW** | **2013 – 2016**

Business Challenges (BC)

BC2 Promote adequate, efficient, and reliable regional transmission in a cost effective manner.

BC4 Link to distribution smart grid
What is the link between bulk transmission system and the evolving distribution smart grid system

BC1 Comply with FERC/NERC/WECC standards and initiatives

BC3 Operational excellence long-term value of transmission assets. Asset management

Operational Challenges (OC)

OC1 Improve the quality of power system models—especially wind power plant models
The technical expertise of generation owners to conduct reliable model validation testing is uneven or inadequate.
[BC2]

OC5 State Estimator is based on insufficiently accurate power flow models
[BC2]

OC3 Better awareness of generating fleet performance requires the ability to continuously monitor generation plants against performance benchmarks
[BC4]

OC2 NERC Standards (MOD 24-27, PRC 19-24) present challenges to BPA's abilities to comply
[BC1]

OC4 NERC San Diego Blackout findings are adding new operations requirements
[BC1, BC3]

Operational & Technical Needs (ND)

ND3 Improve Data Sets
Need data sets with information provided by PMUs to validate against.
[OC1]

ND1 Need to improve the Power-flow Base Case
[OC1,OC3,OC5]

ND2 Need to be able to generate automatic reports for compliance filings
[OC2]

ND4 Model the Distribution System Need ability to model and study Sub 100kv system
[OC4]

Required Capabilities (RC)

RC2 Data mining
Capability to look for events/ disturbances in archived PMU data
[ND3]

RC1 Performance analysis (Work related compliance)
-post-run analysis of cases, including voltage, frequency, damping, impedance, filed current, etc.
- generator control performance assessment
- SPS performance assessment
- in-run analysis, adjust the base case on performance, can use game theory to stress the case and identify vulnerabilities
[ND1]

RC6 Dynamic Models
-Ability to perform a wide range of sensitivities, such as load model composition and protection
[ND1]

RC4 Base cases
- A pre-defined set of base cases, fixed set of pre-contingency outages.
-Automate voltage control adjustment for each base case.
[ND1, ND2]

RC5 Contingency
– Wide range of contingencies, automatic RAS arming
– Prioritize contingencies based on system performance
[ND1, ND2]

RC 9 Additional PMUs
More PMU locations are needed to validate more models
[ND2]

RC3 Reporting
- Tables with system performance assessment
- Sensitivity analysis
- Comparison of several cases
- Plots of predetermined signals
- Plots of violations
[ND2]

Technologies (T)

T1 Advanced software tools
Software that can sort through large amounts (200TB) of PMU data and identify significant events per modeling
[RC1, RC2, RC3, RC6]

T2 A unified modeling approach for both operations and planning which enables convergence of planning and operations.
Methods and tools unify bus/branch and node/breaker models seamlessly What this unified modeling allows is to (directly) compare what planners and operators see without any model conversion, data mapping or manual scripting process.
[RC4, RC5]

R&D Programs (RD)

- Unified Modeling of short- and long-term effects in hydropowerr, Dr. Hans Ivar Skjelbred, Norwegian University of Science and Technology
- Grid Control – A soft platform to support the Smart Grid, Dr. Kenneth Birman, Cornell University and ARPA-E
- Analysis & Control of Smart Electrical Distribution Systems, Sanjay Lall and Dimitry Gorinevsky, Stanford University
- Holomorphic Embedded Load Flow Method Gridquant
- Information and Computation Hierarchy for Smart Grids, Dr. Lang Tong, Cornell University
- The use of telecommunications and GPS technology for the real-time wide-area monitoring and control of power systems Dr. Gerald T. Heydt, ASU
- Gridspice – A virtual platform for modeling, analysis and optimization of the smart grid TomKat Center for Sustainable Energy, Stanford University
- Hierarchical Coordinated Protection of the Smart Grid with High Penetration of Renewable Resources, Dr. Mladen Kezunovic, Texas A&M
- Coordinated Control and Optimization Algorithms for Virtual Power , Dr. Le Xie, Texas A&M
- The Next Generation EMS Design, Dr. Mladen Kezunovic, Texas A&M
- Exploiting Emerging Data for Enhanced Load Modeling (S-49), PSERC
- Architecture and Distributed Management for Reliable Mega-scale Smart Grids, Dr. Vijay Vittal, ASU
- BPA TIP 274 - Development and Demonstration of Applications for BPA and FCRPS Compliance with Modeling Standards and Performance Monitoring (TRL-8)
- BPA TIP 268 - Verification and Validation of Transient Stability Models and Results (TRL-6)

Business Challenge | Operational Challenge | Operational & Technical Need | Required Capability | Technologies | Existing R&D Programs | Non-Existing R&D Programs (Gaps)

Related Internal and External Projects

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Compliance with FERC/NERC/WECC standards and initiatives	NREL PL: Luigi Gentile Polese BPA PM: Mira Vowles 2012 - 2016	**YES**	**TIP 274 - Development and Demonstration of Applications for BPA and FCRPS Compliance with Modeling Standards and Performance Monitoring** The objective of this project is to develop and integrate a comprehensive set of model validation and performance monitoring tools for BPA and Federal Columbia River Power System (FCRPS) participants. The FCRPS participants include Bonneville Power Administration (BPA), US Army Corps of Engineers (US COE) and US Bureau of Reclamations (US BOR) who operate hydro power plants in the Pacific Northwest. Deliverables: ▪ Software for baseline model validation, including documentation and training (SG-1A) ▪ Model library and project set-up for baseline model validation (SG-1B) ▪ Data and model management for Power Plant Model Validation (SG-2A) ▪ Data calibration module (SG-2B) ▪ Software and data set-up for validation of powerflow wind power plant models in BPA system (SG-3A) ▪ Software and data set-up for validation and calibration of dynamic wind power plant models in BPA system (SG-3B and SG-3C) ▪ Software for power plant performance monitoring
Model verification; comparisons with measured data indicate the quality of the overall model	University of Illinois at Urbana-Champaign BPA PM: Terry Doern 2012 – 2014	**YES**	**TIP 268 - Verification and Validation of Transient Stability Models and Results** The first goal of this project is to develop an automated mechanism to verify transient stability simulation packages, used by BPA for their system analyses, against each other. This will be done by simulating WECC power system models in different commercial software packages such as GE-PSLF, PowerWorld Simulator, PowerTech's TSAT and Siemens PTI PSS/E. The overall objective of this proposed work is to bridge the gaps identified in BPA's transmission roadmap and further BPA's cause in optimizing their transmission grid, by facilitating better planning studies and the consequent operational enhancements. This will be attained by increasing the confidence in the dynamic simulation studies of the BPA system, by an integrated software-verification and model-validation approach. Deliverables: Deliverables will include recommendations on how transient stability simulation programs should be modified so that model validation studies can be carried out with ease. At each stage gate, all required and applicable reports, documents and tools will be submitted to BPA for evaluation of sufficient progress. A final report will be provided, describing the execution and achievements of the entire project in detail, as well as charting out the future steps for this work.

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Smart Grid distribution linkage, what is the link between bulk transmission system and the evolving distribution of the Smart Grid system	Cornell University and ARPA-E PL: Kenneth Birman	NO	**Grid Control – A soft platform to support the Smart Grid** Power systems developers will employ GridControl as a tool that simplifies their most challenging problems. It will include new architectural options for power systems monitoring, management and control, and overcome the diverse technical hurdles of cloud computing in real settings. Our effort focuses on putting well understood, working technologies into the hands of development teams seeking to explore innovative power grid control concepts. We argue that such efforts to date have been hobbled by inadequacies in the most common, widely available, production technology platforms. We see ourselves in a role of having fixes for those shortcomings and solutions that already demonstrably bridge this how-to gap. http://www.cs.cornell.edu/Projects/gridcontrol/index.html#impact
	Texas A&M University PL: Le Xie	NO	**Coordinated Control and Optimization Algorithms for Virtual Power**
State Estimators based on insufficient power flow models	Gridquant	NO	**Holomorphic Embedded Load Flow Method (commercial product)** Gridquant physicist Antonio Trias Bonet invented the algorithms and proved them internationally for a decade. They are unlike existing approaches that require some prior knowledge of the condition of the grid in order to ascertain load flow and state estimation, yielding uncertain and unreliable results. The advanced grid management tools based on HELM allow grid operators to accurately monitor and control the power grid under all operating conditions. (News: Battelle has signed an exclusive licensing and collaboration agreement with the specialty grid management company Gridquant, bringing breakthrough modeling and analysis technologies to the electricity transmission market.)
Smart Grid distribution linkage, what is the link between bulk transmission system and the evolving distribution of the Smart Grid system	Texas A&M University PL: Mladen Kezunovic	NO	**Hierarchical Coordinated Protection of the Smart Grid with High Penetration of Renewable Resources**
Ability to promote adequate, efficient, and reliable regional transmission in a cost effective manner	PSERC PL: Mladen Kezunovic (Texas A&M University)	NO	**The Next Generation EMS Design (T-45)** The concept of Energy Management Systems (EMS) was introduced in the late sixties and was not changed much until today. In the mean time many new infrastructure concepts and solutions emerged. Future EMS design that embraces emerging infrastructures and applications will be outlined.

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Inadequate technical expertise of generation owners' to conduct reliable model validation testing	Norwegian University of Science and Technology PL: Hans Ivar Skjelbred,	**NO**	**Unified Modeling of short- and long-term effects in hydropower** Traditional modeling of hydropower systems consist of a two-step process. The first part is a strategic analysis of seasonal inflow producing water values as guidelines for reservoir utilization. In the second part these guidelines are used as input for a short-term model with a finer resolution resulting in a detailed operating strategy. In this paper a modeling approach is presented unifying the previously decoupled parts into an Lagrange relaxation scheme incorporating the short term operating in the long term guidelines and vice versa.
Smart Grid distribution linkage, what is the link between bulk transmission system and the evolving distribution of the Smart Grid system	Center Stanford University PL: Sanjay Lall Dimitry Gorinevsky TomKat	**NO**	**Analysis & Control of Smart Electrical Distribution Systems** This research focuses on the development of systems analysis, control, and monitoring technologies for the distribution segment of the electrical grid. This is one of the parts of the grid where there is substantial need and opportunity for technological enhancement. The primary purpose of this research is to address the impact on the system of future distributed renewable generation, storage, demand management, and electric vehicle charging systems. Our approach is based on computational analysis and simulation, making use of dynamical models, statistical inference, and optimization.
Smart Grid distribution linkage, what is the link between bulk transmission system and the evolving distribution of the Smart Grid system	ASU PL: Gerald T. Heydt	**NO**	**The use of telecommunications and GPS technology for the real-time wide-area monitoring and control of power systems** This project will contribute to the advancement of knowledge in the areas of security, monitoring and control of power systems by utilizing the SMT technology. The methodologies developed, will be tested on IEEE test systems and on the Cyprus power system. It is envisioned that with the completion of this project, the reliability of the power system will be further enhanced, promoting the quality of life and welfare of the citizens.
Smart Grid distribution linkage, what is the link between bulk transmission system and the evolving distribution of the Smart Grid system	Center for Sustainable Energy, Stanford University PL: TomKat	**NO**	**Gridspice – A virtual platform for modeling, analysis and optimization of the smart grid** The project aims to research and begin prototype development of GridSpice, a software simulation system for modeling, design, planning and optimization of the smart grid. GridSpice will model the interactions between all parts of the electrical network–including generation, transmission, distribution, storage and loads; in addition, it will also model the wholesale and retail electricity markets, and response of consumers to price sensitive contracts.
Smart Grid distribution linkage, what is the link between bulk transmission system and the evolving distribution of the Smart Grid system	ASU PL: Vijay Vittal 2010 - 2013	**NO**	**Architecture and Distributed Management for Reliable Mega-scale Smart Grids** The objective of this research is to establish a foundational framework for smart grids that enables significant penetration of renewable DERs and facilitates flexible deployments of plug-and-play applications, similar to the way users connect to the Internet. The approach is to view the overall grid management as an adaptive optimizer to iteratively solve a system-wide optimization problem, where networked sensing, control and verification carry out distributed computation tasks to achieve reliability at all levels, particularly component-level, system-level, and application level.

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Smart Grid distribution linkage, what is the link between bulk transmission system and the evolving distribution of the Smart Grid system	Cornell University PL: Lang Tong (NSF-CPS-1135814) 2011 - 2015	**NO**	**Information and Computation Hierarchy for Smart Grids** This research investigates key aspects of a computation and information foundation for future cyber-physical energy systems - the smart grids. The overall project objective is to support high penetrations of renewable energy sources, community based micro-grids, and the widespread use of electric cars and smart appliances. http://sensorweb.cs.gsu.edu/?q=SmartGrid
State Estimators based on insufficient power flow models	PSERC	**NO**	**Exploiting Emerging Data for Enhanced Load Modeling (S-49)** This project investigates mechanisms to exploit emerging PMU and smart meter datasets to enhance load and demand modeling. The new datasets contain a wealth of information yet unexplored, which can provide the means for powerful load analytics, and a platform for the development of novel power system analysis methods. This project addresses three key challenges in power systems load modeling that can be overcome by relying on novel data and recent algorithms: a) PMU-based dynamic load modeling and dynamic state estimator, b) Smart meter-based load modeling and analytics through data mining, and c) Signature-based load identification and sensing requirements for load composition determination. The enhanced load models and load modeling methodologies resulting from this research will provide superior understanding of emerging power system behavior, and better models for enhanced control, operations, and power system planning.

II. Transmission Operations

Intelligent Alarms Roadmap

Business and Technology Challenges

With hundreds of different processes running at once, operators can be hard pushed to keep up with alarms, even under normal conditions. Without careful management, alarms can be ignored by even the most diligent of operators. Persistently active alarms may even be disabled, leading to vulnerabilities and risks must be quickly and accurately identified and understood. Intelligent alarms should start by exploring how operators make decisions during critical conditions, how they and the system learn to improve decisions, realizing false and extraneous (to the situation) alarms and data need to be identified and either corrected or identified and suppressed.
To ensure the operational goals and decision processes (the decision may be different depending on the goal and system state), and what understanding can be achieved from emerging sensing.

Operational challenges are as follows:

- Large amounts of signals and alarm information can make it difficult for operators to make emergency control and restoration decisions. Too much data is as bad as too little.
- Secondary circuit signals can be redundant, confusing diagnosis of faults and leading to mistaken alarms.
- State Awareness to delineate normal from abnormal conditions.
- Lessons learned for other from other outages eg San Diego and identifying issues important to BPA.
- Cannot get accurate line connect and disconnect status for state estimator in some cases.
- Communication issues with unmanned Substations where alarms must be sent to control centers.
- Prioritization and Filtering of alarms must be categorized or otherwise processed such that system problems can identify and resolved.
- Alarm standardization and descriptions are not consistent across the system.

R&D Gaps

Business and Technological Challenges which are not addressed by existing R&D programs:

1. Protective Relay Events
   - Technologies that make better use of event reports that are recorded in protective relays.

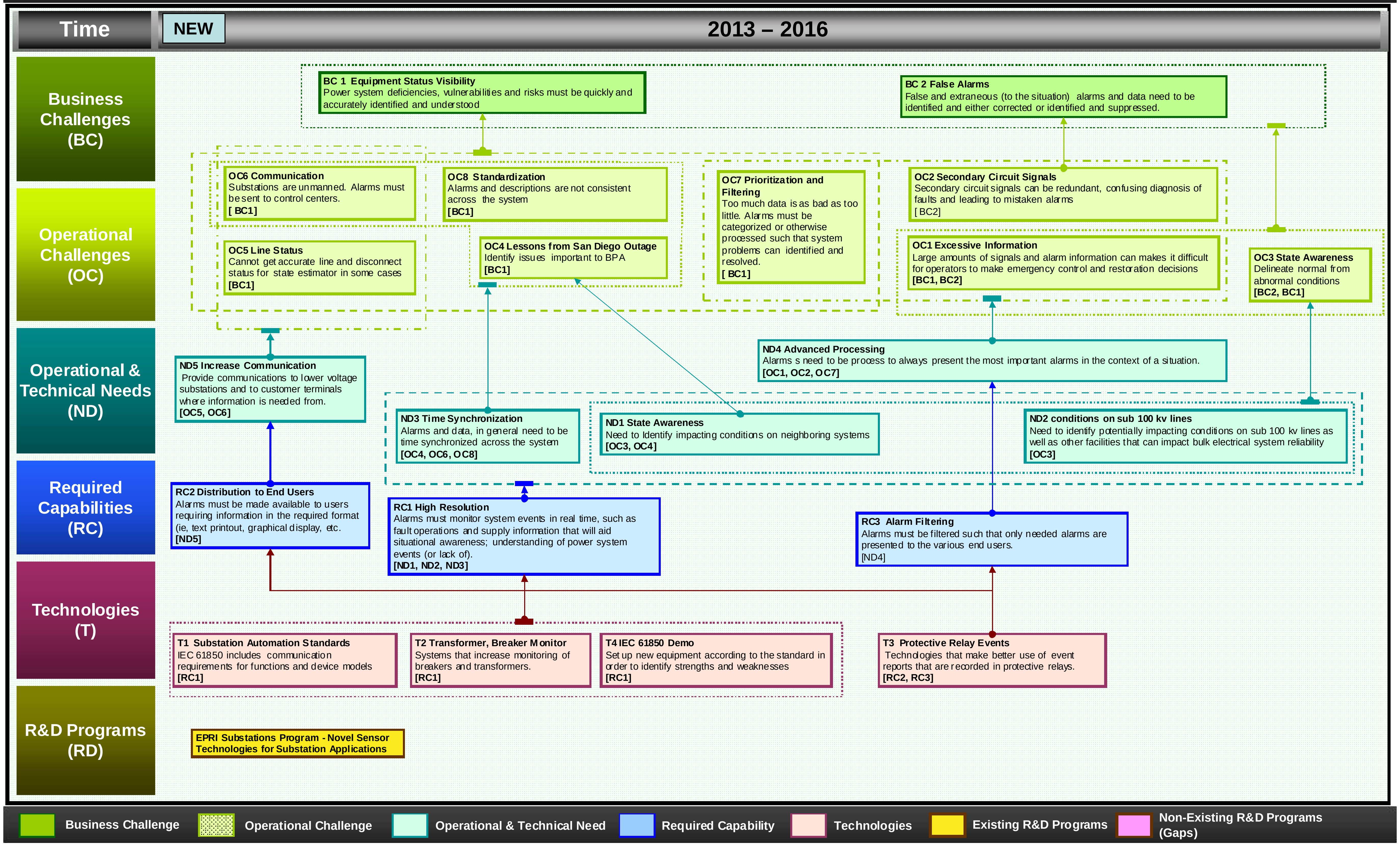
Business and Technological Challenges which are covered partially by existing R&D programs but still require further research and development:

1. Transformer, Breaker Monitor
   - Systems that increase monitoring of breakers and transformers.
2. Substation Automation Standards
   - IEC 61850 includes communication requirements for functions and device models .

Business and Technological Challenges which are covered by commercialized technologies and products, however demonstration or confirmation studies may be required:

- None

II-1. Intelligent Alarms Technology Roadmap



Related Internal and External Projects

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Identify what can be achieved from emerging sensing	EPRI (Published 12/21/2011)	**NO**	**EPRI Substations Program - Novel Sensor Technologies for Substation Applications** The objective of this report is to provide an overview of existing and potential applications for sensors at substations and to present pertinent information about sensor use outside the power industry to enable personnel to become more aware of present and future technologies that they may wish to implement.

III. Power Grid Optimization

Power Flow Controls Roadmap

Business and Technology Challenges

A critical challenge in Transmission Monitoring & Control Systems is transmission system capacity – we need to increase capacity of the transmission system without extensive capital investment.

This creates multiple operational challenges:

- Network Capacity Limitations: A network increases reliability at the cost of capacity underutilization and inefficiency. In a transmission grid, capacity is limited by the lowest-capacity segment. Electricity follows a “path of least resistance” (lowest impedance), so the first line to reach its thermal capacity limits the capacity of the entire system, even though a majority of the lines of the system may be significantly below their limit.
- Voltage Stability: Increased application of variable energy resources balanced within-hour by remote conventional resources adds additional variation to power flows and voltage support capabilities.

These challenges result in the following operational and technical needs:

- Control Power Flows: Having the ability to explicitly control power flow could enable accessing this unused capacity to relieve congestion, relieve outage constraints and improve system security as an alternative to new transmission lines
- Voltage Controls: Major load service paths that are voltage stability limited may require additional devices that control voltage variability.

Required capabilities to fulfill the needs are:

- Power Flow System Components for Grid Optimization: Need to understand what devices are available, what are their operating characteristics, where to put them, and what sizes (capabilities) are needed. Much longer long term assessment and evaluation of interactions.
- Automated Controls: Automated controls must be able to handle sudden events (unplanned outages) or unexpected operating conditions in ways that don’t disturb the rest of the system.
- System Expansion & Optimization: Optimization of the existing system, increase in number of lines & interconnections by about 10%. Control power flow and Optimize RAS
- Identifying a good application, with high quality studies to support its performance (Planning focus), and show this application has a higher value than a traditional solution (new line, substation, or transformer), a well informed sound business case

Related technology is power flow control/flexible alternating current transmission system (FACTS) devices. HVDC (back to back or AC to DC conversion, voltage source conversion) phase shifting, impedance changing technologies

R&D Gaps

Business and Technological Challenges which are not addressed by existing R&D programs:

1. Network Capacity Limitations
2. System Expansion & Optimization
3. Automated Controls
4. Response based controls

Business and Technological Challenges which are covered partially by existing R&D programs but still require further research and development:

1. Control Power Flows
2. Power Flow System Components for Grid Optimization
3. Voltage Stability
4. Voltage Controls

Business and Technological Challenges which are covered by commercialized technologies and products, however demonstration or confirmation studies may be required:

1. New technologies – A high-power circuit breaker
2. Relatively new technologies – voltage source converters and distributed FACTS (Smart Wire)
3. Improved existing technologies – phase shifting transformers, switchable series inductors/capacitors or thyristor controlled, and FACTS

III-1. Power Flow Controls Technology Roadmap

Time: 2012 – 2015

Business Challenges (BC)

BC1 Transmission System Capacity
Increase capacity of the transmission system without extensive capital investment

Operational Challenges (OC)

OC1 Meshed Network Limits Capacity
A meshed network increases reliability at the cost of capacity underutilization and inefficiency. In a meshed transmission system, capacity is limited by the lowest-capacity segment. Electricity follows a "path of least resistance" (lowest impedance), so the first line to reach its thermal capacity, limits the capacity of the entire system, even though a majority of the lines of the system are significantly below their limit.

OC2 Voltage Stability
Increased application of variable energy resources balanced within-hour by remote conventional resourced adds variation to power flows and the ability to provide voltage support.

Operational & Technical Needs (ND)

ND 1 Control Power Flows
Having the ability to explicitly control power flow would enable accessing this unused capacity to relieve congestion, relieve outage constraints and improve system security as an alternative to new transmission lines.

ND2: Voltage Controls
Major load service paths that are voltage stability limited require additional cost effective devices that control voltage variability

Required Capabilities (RC)

RC1 Power Flow System Components for Grid Optimization
Need to understand what devices are available, where to put them, and what sizes (capabilities) are needed. Much longer long term assessment and evaluation of interactions.

RC2 Automated Controls must not make Problems Worse
Automated controls must be able to handle sudden events (unplanned outages) or unexpected operating conditions in ways that don't disturb the rest of the system.

RC3 System Expansion & Optimization
Optimization of the existing system, increase in number of lines & interconnections by about 10%. Control power flow and Optimize RAS

Technologies (T)

T1 Power Flow Controls/Flexible Alternating Current Transmission System (FACTS) devices
Power flow control devices steer the current in a line in order to balance the loading on all the lines allowing the overall system to operate at its theoretical maximum capacity.

R&D Programs (RD)

- PSERC: Evaluation of RTV Coated Station Insulators (T-46G)
- BPA TIP 245 CONTROL OF POWER FLOW CONTROL DEVICES (TIP-4)
- PSERC: Setting-less Protection Methods (S-48G)
- PSERC: Seamless Power System Analytics (S-46G)
- PSERC: Micro and Nano Dielectrics for Utility Applications (T-42)
- ARPA-E: Compact Dynamic Phase Angle Regulators for Transmission Power Routing
- EPRI: Overhead Transmission - Program 35 (2011-2013)
- BPA TIP 46 Operations real time study process improvement (TRL-8)
- BPA TIP 241: Evaluation of power flow controls, demand response and energy storage opportunities for resolving transmission constraints in the pacific northwest (TIP-7)
- ARPA-E: Robust Adaptive Topology Control (RATC)
- ARPA-E: Magnetic Amplifier for Power Flow Control
- ARPA-E: Resilient Multi-Terminal HVDC Networks with High-Voltage High-Frequency Electronics
- EPRI: HVDC and FACTS Technologies - Program 162 (2011
- BPA TIP 50 Power system controls- inter area oscillation damping (TRL-9)
- BPA TIP 51 - RESPONSE BASED VOLTAGE STABILITY CONTROLS (TRL-9)
- ARPA-E: Transformer-less Unified Power Flow Controller for Wind and Solar Power Transmission
- ARPA-E: Scalable Real-time Decentralized Volt/VAR Control
- BPA TIP 282 - Transmission Power Flow Controls for Bulk Grid Optimization (TIP-6)
- BPA TIP 268 - Verification and Validation of Transient Stability Models and Results (TRL-6)
- BPA TIP 237 Bidirectional multipath dynamic transfer analysis (TIP-4)
- ARPA-E: Prosumer-Based Distributed Autonomous Cyber-Physical Architecture for Ultra-reliable Green Electricity Internetworks
- ARPA-E: Distributed Power Flow Control Using Smart Wires for Energy Routing
- Transmission Topology Control for Infrastructure Resilience to the Integration of Renewable Generation ARPA-E
- ABB tests out high-voltage direct-current circuit-breakers at their facility
- PSERC: Validation and Accreditation of Transient Stability Results (S-43G)

Legend: Business Challenge | Operational Challenge | Operational & Technical Need | Required Capability | Technologies | Existing R&D Programs | Non-Existing R&D Programs (Gaps)

Related Internal and External Projects

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Increased application of variable energy resources balanced within-hour by remote conventional resources adds additional variation to power flows and voltage support capabilities.	BPA PL: Dmitry Kosterev	**YES**	**TIP 51 - Response Based Voltage Stability Controls** This project researches all three types of controls (primary, secondary, emergency) will be considered. Primary Voltage control - Response-based controls for fast reactive switching of 500-kV shunt capacitor banks in Portland / Salem area. Coordination reactive resources in Southern Oregon / Northern California area. Secondary Voltage Controls - Reactive power management to optimize voltage profile and to maximize reactive margins. Emergency voltage controls - Low voltage shedding. Key Results/Conclusions: ▪ A combination of model-based stability assessment, measurement based tools and response-based Remedial Action Scheme (RAS) are needed to address voltage stability limits. ▪ Operational tools: Several measurement-based tools have been researched and are currently in the prototype phase. ▪ Response-based RAS: Wide-area control system is under the development. WACS will be deployed under the synchro-phasor capital program. California-Oregon Intertie reactive coordination studies are in progress. ▪ Wind power plant voltage controls: Voltage control requirements are developed. Secondary voltage control studies are planned. ▪ Load-Induced voltage instability: Load models are developed by WECC. BPA did significant amount of equipment testing, model development and data preparation. Studies indicate that the Portland metro may be at risk of voltage instability due to air-conditioner stalling. The project supports the development of regulatory framework which will have huge impact on the capital investment needs. ▪ Analysis tools: Tools for analysis of wind power plant voltage controls. ▪ Time-sequence power flow: Time-sequence powerflow capabilities in Power World and PSLF; also, the time sequence for studying the impact of wind ramp events on system voltage stability.
Need to increase capacity of the transmission system without extensive capital investment	BPA PL: Travis Togo	**YES**	**TIP 241 - Evaluation of Power Flow Controls, Demand Response And Energy Storage Opportunities For Resolving Transmission Constraints in the Pacific Northwest** The proposed project will 1) Develop the framework and methodology for evaluating powerflow control and load control options in the transmission planning process – i.e. expanding the toolbox of the transmission planners to include applicable non-wire solutions, 2) Test the methodology to size up powerflow control and load control options for a) Portland metro area, b) Seattle / Northern Intertie, c) Export capability out of Pacific Northwest, 3) Study feasibility of various powerflow control and load control options, and 4) Evaluate control strategies. Key Results/Conclusions: ▪ Methodology Draft, Regulatory Framework Assessment ▪ System impact studies for power flow controls ▪ Feasibility assessment ▪ Control Simulations ▪ Final Methodology, Study and Business Case Guidelines

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Power Flow System Components for Grid Optimization - Need to understand what devices are available, what are their operating characteristics, where to put them, and what sizes (capabilities) are needed.	BPA PL: Paul Ferron 2011 - 2012	**YES**	**TIP 245 - Control of Power Flow Control Devices** The objective of this project is to investigate the effectiveness of power flow control devices such as FACTS devices with regards to congestion management and improving the usage of the existing transmission system. This will allow providing a more flexible system and pushing more power through the existing lines. We will derive the schemes to determine the optimal settings of the power flow control devices taking into account the varying power injections from intermittent and variable generation resources such as wind and solar generation. Key Results/Conclusions: ▪ White Paper, approximately10 pages, documenting test system used, justification for objective function and description of method used for sensitivity analysis. ▪ Interim Report, approximately 15 pages. Description of decentralized control methodology including simulation results comparing achieved results with results of Optimal Power Flow. ▪ Final Report, approximately 50 pages. Detailed report on project tasks carried out, results of system studies and conclusions on effectiveness of power flow control devices in the proposed application. ▪ Simulation code software including detailed comments. ▪ Presentation of accomplished work including explanation of simulation code.
Control power flows	ARPA-E Texas Engineering Experiment Station	**NO**	**Robust Adaptive Topology Control (RATC)** Historically, the electric grid was designed to be passive, causing electric power to flow along the path of least resistance. The Texas Engineering Experiment Station team will develop a new system that allows real-time, automated control over the transmission lines that make up the electric power grid. This new system would create a more robust, reliable electric grid, and reduce the risk of future blackouts, potentially saving billions of dollars a year.
Control power flows	ARPA-E Michigan State University	**NO**	**Transformer-less Unified Power Flow Controller for Wind and Solar Power Transmission** Michigan State will develop a unified power flow controller (UPFC) that will have enormous technological and economic impacts on controlling the routing of energy through existing power lines. The UPFC will incorporate an innovative circuitry configuration that eliminates the transformer, an extremely large and heavy component, from the system. As a result, it will be light weight, efficient, reliable, low cost, and well suited for fast and distributed power flow control of wind and solar power.
Control power flows	ARPA-E Oak Ridge National Laboratory	**NO**	**Magnetic Amplifier for Power Flow Control** Complete control of power flow in the grid is prohibitively expensive, which has led to sub-optimal, partial control. Oak Ridge National Laboratory will develop a magnetic based valve-like device for full power flow control. The controller will be inherently reliable and cost-effective, making it amenable for widespread distributed power flow control. The benefits are far-reaching, including full utilization of power system assets, increased reliability and efficiency, and more effective use of renewable resources.

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Control power flows	ARPA-E Georgia Tech Research Corporation	**NO**	**Prosumer-Based Distributed Autonomous Cyber-Physical Architecture for Ultra-reliable Green Electricity Internetworks** Georgia Tech will develop and demonstrate an internet-like, autonomous control architecture for the electric power grid. The architecture has distributed intelligence, autonomously coordinating control within a network that includes energy production units, storage units, and consumers (homes, buildings, microgrids, utility systems). It will reduce constraints on grid control and enable massive penetration of distributed energy resources (primarily wind and solar power) and storage devices (such as batteries).
Control power flows	ARPA-E Smart Wire Grid, Inc	**NO**	**Distributed Power Flow Control Using Smart Wires for Energy Routing** Over 660,000 miles of transmission line exist within the continental United States with roughly 33% of these lines experiencing significant congestion. This congestion exists while, on average, only 45-60% of the total transmission line capacity is utilized. A team led by startup company Smart Wire Grid will develop a solution for controlling power flow in the transmission grid to better take advantage of the unused capacity. The power controller will be a "smart wire" that incorporates advanced control software, sensors, and communications technologies.
Power flow system components for grid optimization	ARPA-E California Institute of Technology	**NO**	**Scalable Real-time Decentralized Volt/VAR Control** Caltech will develop scalable, real-time, decentralized methods for power control to achieve system-wide efficiency, stability, reliability, and power quality in the presence of uncertain renewable generation. The distributed control architecture will allow each of the end nodes to effectively manage their own power, while at the same time optimizing overall power flow within the grid. This will enable an interconnected system with millions of active energy applications, such as distributed wind and solar power units.
Power flow system components for grid optimization	ARPA-E General Electric Company-Global Research	**NO**	**Resilient Multi-Terminal HVDC Networks with High-Voltage High-Frequency Electronics** Some advanced transmission technologies require expensive power conversion stations to interface with the grid. GE Global Research will collaborate with North Carolina State University (NCSU) and Rensselaer Polytechnic Institute (RPI) to develop a prototype transmission technology that incorporates an advanced semiconductor material, silicon carbide. This prototype will operate at a high voltage level appropriate for the grid. It will decrease the cost and complexity of advanced transmission systems as well as improve efficiency.
Control power flows	ARPA-E Varentec, Inc.	**NO**	**Compact Dynamic Phase Angle Regulators for Transmission Power Routing** Varentec will develop a compact, low-cost solution for controlling power flow on transmission networks. The technology will enhance grid operations through improved asset utilization and by dramatically reducing the number of transmission lines that have to be built to meet increased renewable energy penetration. Finally, the ability to affordably and dynamically control power flow will open up new competitive energy markets which were not possible under the current regulatory structure and technology base.

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Increase capacity of the transmission system without extensive capital investment	EPRI	**NO**	**Overhead Transmission - Program 35 (2011-2013)** Transmission companies face issues such as improving safety and reliability, as well as cutting operations and maintenance (O&M) costs. They are also seeking ways to increase transmission capacity without making large capital investments. Reducing capital expenditures for new and refurbished equipment is another priority. This EPRI research program is designed to address the research needs of transmission asset owners. The program includes projects focused on specific components (e.g., insulators, compression connectors and crossarms) as well as projects focused on issues (e.g., lightning and grounding, live working, and transmission capacity). The program delivers a blend of short-term tools such as software, reference guides and field guides, together with longer-term research such as component aging tests and the development of sensors for monitoring line components and performance.
Control power flows	EPRI	**NO**	**HVDC and FACTS Technologies - Program 162 (2011** The power industry is faced with the difficulty of acquiring rights-of-way for new transmission lines, the need to improve the reliability of the power grid, and the challenge of integrating renewable power sources into power systems. High-voltage direct current (HVDC) and flexible ac transmission system (FACTS) technologies offer some effective schemes to meet these demands. Applying HVDC technologies within an existing ac system is an option that can increase the transmission capacity of the existing power system. HVDC technologies can also be applied to the power system to improve system reliability. HVDC may provide solutions in integrating renewable power sources such as wind and solar energy into a power system. FACTS is an effective means of managing power flows. Both HVDC converters and FACTS share some common technologies. This program offers a comprehensive portfolio of HVDC and FACTS research, consisting of two HVDC project sets and one FACTS project set. Participants can apply program research to existing and future power systems, and better understand the options of using these technologies when evaluating these systems.
Power flow system components for grid optimization	PSERC PL: Tom Overbye (University of IL/Urbana)	**NO**	**Validation and Accreditation of Transient Stability Results (S-43G)** Determination of the transient stability properties of a power system for a set of contingencies is of vital importance. However, it is widely known in the industry that different transient stability packages can give substantially different results for seemingly identical models. The goal of this project is to develop validation and accreditation methodologies for transient stability packages with a focus on the Western Electricity Coordinating Council (WECC) system models. Different commercial transient stability packages will be utilized for testing and comparisons.
Need to understand what devices are available, what are their operating characteristics, where to put them, and what sizes (capabilities) are needed	PSERC PL: A. P. Sakis Meliopoulos (Georgia Institute of Technology)	**NO**	**Setting-less Protection Methods (S-48G)** The capabilities of protective relays have increased dramatically as higher and higher end microprocessors are used in modern numerical relays. At the same time the complexity has increased primarily because numerical relays are set to mimic the traditional electromechanical counterparts. We propose to examine approaches that will lead to setting-less protection schemes. Several approaches will be examined: (a) adaptive relaying, (b) component state estimation approach, (c) substation based protection, and pattern recognition based approach. Each approach will be evaluated with the following criteria: (a) feasibility, (b) dependability, (c) security, (d) reliability, and (e) speed of protection. It is expected that these approaches will lead to true setting-less protection schemes.

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Power Flow System Components for Grid Optimization, Automated controls, System Expansion & Optimization	PSERC PL: James McCalley (Iowa State University)	**NO**	**Seamless Power System Analytics (S-46G)** The current approach to power system analysis has developed over the last 3-4 decades in a piecemeal approach where the various applications run separately using their own system models and formats. Although these tools have improved, the programs are still built upon core technology and software architectures from decades ago, each developed for its own unique purpose rather than an integrated approach that builds upon state-of-the-art algorithms, hardware, and modern day methods for data management across a shared environment. These limitations need to be overcome by modern analytical tools that can support modernization of the electricity industry. This project will identify design requirements to transition to a new systems analysis platform that encapsulates a comprehensive power system model with seamless analytics. Design requirements are organized as: (a) types of organizations and analysis needs of each; (b) computing applications associated with each analysis need; (c) basic functions comprising each computing application; (d) algorithm/hardware combinations associated with each function; (e) software architecture designs to facilitate seamless and computationally efficient power system analysis.
Need to understand what devices are available, what are their operating characteristics, where to put them, and what sizes (capabilities) are needed	BPA 2012-2014	**YES**	**TIP 282 - Transmission Power Flow Controls for Bulk Grid Optimization** The project will test the hypotheses that a well planed transmission upgrade adding power flow control to the main grid can provide an increase to operating transfer capability (OTC) and total transfer capability (TTC), while maintaining or increasing reliability and operating flexibility, at a better benefit/cost ratio than a new line build addressing the same constraints. The final goal is to provide a list of projects that have tested results and are available for Transmission Planning to move into the Planning Process, as determined appropriate. Deliverables: ▪ At the end of stage 1 a white paper on modern power flow control applications will be provided. The white paper will summarize the applications, costs, life cycle, operations, maintenance, and first hand utility experiences with the different devices used to control power flow across transmission systems. ▪ In stage 1 power flow studies will be evaluate the performance of power flow control solutions on the BPA system. ▪ In stage 2 a more detailed set of studies will consider the impacts to system stability and control of the solutions identified. ▪ In phase 3 the work moves into a development effort. A feasibility analysis of the most promising projects identified from phase 1 and phase 2 will be performed. ▪ For any software enhancements pursued, documentation of the improvement and a presentation will be prepared for the transmission study staff at BPA. The goal of this deliverable will be to ensure this enhancement is well communicated to the staff that will benefit from its development.

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Power flow system components for grid optimization	University of Illinois at Urbana-Champaign	YES	**TIP 268 - Verification and Validation of Transient Stability Models and Results** The first goal of this project is to develop an automated mechanism to verify transient stability simulation packages, used by BPA for their system analyses, against each other. This will be done by simulating WECC power system models in different commercial software packages such as GE-PSLF, PowerWorld Simulator, PowerTech's TSAT and Siemens PTI PSS/E. . The overall objective of this proposed work is to bridge the gaps identified in BPA's transmission roadmap and further BPA's cause in optimizing their transmission grid, by facilitating better planning studies and the consequent operational enhancements. This will be attained by increasing the confidence in the dynamic simulation studies of the BPA system, by an integrated software-verification and model-validation approach. Deliverables: Deliverables will include recommendations on how transient stability simulation programs should be modified so that model validation studies can be carried out with ease. At each stage gate, all required and applicable reports, documents and tools will be submitted to BPA for evaluation of sufficient progress. A final report will be provided, describing the execution and achievements of the entire project in detail, as well as charting out the future steps for this work.
A network increases reliability at the cost of capacity underutilization and inefficiency	ARPA-E Charles River Associates International, Inc. (CRA)	NO	**Transmission Topology Control for Infrastructure Resilience to the Integration of Renewable Generation** The CRA team is developing control technology to help grid operators more actively manage power flows and integrate renewables by optimally turning on and off entire power lines in coordination with traditional control of generation and load resources. The control technology being developed would provide grid operators with tools to help manage transmission congestion by identifying the facilities whose on/off status must change to lower generation costs, increase utilization of renewable resources and improve system reliability. The technology is based on fast optimization algorithms for the near to real-time change in the on/off status of transmission facilities and their software implementation.
Power flow system components for grid optimization	ABB ***http://www.abb.com***	NO	**ABB tests out high-voltage direct-current circuit-breakers at their facility** ABB, the large power and automation company, has developed technology that could provide an efficient way to transmit power from widely distributed solar panels, wind turbines, and other sources of renewable energy. The new technology is a fast and efficient circuit breaker for high-voltage direct-current (DC) power lines, a device that has eluded technologists for 100 years. The breaker makes it possible to join high-voltage DC transmission lines to form a resilient power grid. Within five milliseconds it can stop the flow of a huge amount of power—equal to the entire output of a nuclear power plant. The breakers could be used to nearly instantaneously reroute power in a DC grid around a problem, allowing the grid to keep functioning. http://www.technologyreview.com/news/507331/abb-advance-makes-renewable-energy-supergrids-practical/

Power System Stability Controls

Business and Technology Challenges

One of the critical challenges in Transmission Monitoring & Control Systems, is Managing System Disturbances. System reliability and throughput can be increased by utilizing synchrophasor. It also improves wide area and response based controls. Also, the electric system can be protected against extreme events by using Synchrophasor data. Human performance and system complexity must be evaluated to minimize reliability risks.

Specific operational challenges include:

- Protection of load voltage, and ensure sufficiency of safety-nets.
- Transformer protection against GIC

Operation and technical needs related to the challenges include:

- Ensure Sufficiency of Safety-Nets**:** Safety Nets are protective schemes designed to localize disturbances and the uncontrolled loss of generation, transmission and interruption of customer electric service. They are needed to minimize and reduce the severity of low probability, unforeseen events to prevent cascading.
- Managing impacts of GIC events (Geomagnetically Induced Current)
  - GIC transformer protection strategy
  - GIC Reactive control strategy

The following are specific technology capabilities needed:

- Manage RAS-initiated responses to system disturbances such as Generation Drop and Reactive Switching to match the actual system needs (not the pre-Armed RAS conditions)
- Minimize excessive RAS generation drop
- Sense power system oscillation modes (0.25-0.8 Hz), and mitigate with new oscillation damping equipment
  - Modulated Brake, generation controls, HVDC, WACS/RAS enhancements etc.

Technologies capable of dealing with GIC events should be able to manage:

- Increased relative VAR demand
- Increased harmonics that impact reactive support elements of the bulk electrical system (SVC, capacitor banks, and filter groups).
- Increased thermal stress on transformers due to internal heating by stray flux during the saturated portion of the AC cycle.

R&D Gaps

Business and Technological Challenges which are not addressed by existing R&D programs:

1. Manage RAS-initiated responses to system disturbances
2. Minimize excessive RAS generation drop
3. Transformer protection for GIC or impending future
4. GIC Reactive control strategy
5. Impact of GIC Harmonics on FACTS, HVDC controls, protective relays

Business and Technological Challenges which are covered partially by existing R&D programs but still require further research and development:

1. Protection of load voltage
2. Ensure Sufficiency of Safety-Nets
3. Managing impacts of GIC events
4. Sense power system oscillation modes, and mitigate with new oscillation damping equipment

Business and Technological Challenges which are covered by commercialized technologies and products, however demonstration or confirmation studies may be required:

- None

III-2. Power System Stability Controls Technology Roadmap

Time: 2012 – 2015

Business Challenges (BC)

BC1 Response-based Controls
Utilize capabilities provided by syncrophasor technology. (S/M/L)

BC2 Wide Area Controls
Using syncrophasor data to protect against extreme events such as blackout etc. (S/M/L)

Operational Challenges (OC)

OC1 Protection of load voltage, and sufficiency safety-nets is a new world to BPA

OC2 Transformer protection for GIC or impending future

Operational & Technical Needs (ND)

ND1 Equipment upgrade
New controls to existing equipment including DC terminal

ND3 DC Ensure Sufficiency of Safety-Nets

ND4 Managing impacts of GIC events

ND2 New Equipment
Need new equipment and testing tools to control power system.

Required Capabilities (RC)

RC1: Manage RAS Gen Drop and Reactive Switching to match the response to actual system needs (not pre-Armed RAS)

RC2: Minimize excessive RAS generation drop

RC3: Sense power system oscillation modes (0.25-0.8 Hz), and mitigate with new oscillation damping equipment.

RC4: Increased relative VAR demand

RC5: Increased harmonics that impact reactive support elements of the bulk electrical system

RC6: Increased thermal stress on transformers due to internal heating by stray flux during the saturated portion of the AC cycle

Technologies (T)

T1: Modulated Brake, gen controls, HVDC, WACS/RAS enhancements etc.

R&D Programs (RD)

- BPA TIP 50: Power system controls-inter area oscillation damping (TRL-9)
- BPA TIP 35: PNW SMART GRID DEMONSTRATION PROJECT (TRL-8)
- BPA TIP 46: OPERATIONS REAL TIME STUDY PROCESS IMPROVEMENT (TRL-8)
- BPA TIP 289 - Wide Area Damping Control Proof-of-Concept Demonstration (TRL-6)
- BPA TIP 275 - New remedial action scheme (RAS) research work to avoid cascading caused by intermittent output of renewable energy resources (TRL-3)
- BPA TIP 51: Response based voltage stability controls (TRL-9)
- PSERC: Testing and Validation of Phasor Measurement Based Devices and Algorithms (S-45)
- PSERC: Data Mining to Characterize Signatures of Impending System Events or Performance from PMU Measurements (S-44)
- Real Time PMU-Based Stability Monitoring (S-50), PSERC
- BPA TIP 244: Advanced life extending control of multiple energy storage solutions (TIP-4)
- PSERC: Impact of Bad Data and Cyber Data Attack on Electricity Market Operation (M-27)
- PSERC: Verifying Interoperability and Application Performance of PMUs and PMU-Enabled IEDs at the Device and System Level (T-43)

Business Challenge | Operational Challenge | Operational & Technical Need | Required Capability | Technologies | Existing R&D Programs | Non-Existing R&D Programs (Gaps)

Related Internal and External Projects

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Oscillation detection; Voltage stability (generator voltage control tool); effective phase angle alarm and data mining tool.	BPA PL: Dmitry Kosterev	**YES**	**TIP 50 - power system controls- inter area oscillation damping** This project will research devices and control schemes that can greatly improve damping of inter-area power oscillations. The primary focus is on North-South power oscillations, affecting California - Oregon Intertie. The secondary focus is on East - West oscillations affecting Montana imports into Pacific Northwest. The project methods are the Assessment of Grid Component Capabilities and Investigation of Wide Area Control Configurations. Deliverables: ▪ System-Level Oscillation Damping Controls ▪ Supply-Side Oscillation Damping Controls ▪ Demand Side Solutions ▪ Ambient and Event Based Mode Monitoring
Utilization of the synchrophasor technology can be improved by leveraging wide area and response based controls	BPA PL: Lee Hall	**YES**	**TIP 35 - PNW smart grid demonstration project** The project expands upon the region's experience in the 2006 DOE-funded Pacific Northwest GridWise™ Demonstration Project on the Olympic Peninsula, which successfully tested demand response concepts and technologies. BPA's role is to coordinate with Battelle and participating utilities to develop a smart grid business case based on data from utilities, customers and project vendors to inform a cost benefit analysis. Lead public outreach and communication with governments (states, Northwest delegation, Tribes, others), non-partner utilities, educational institutions, energy and regulatory organizations (WECC, NERC, NWPCC, NWPPA, etc.), the general public and other regional demonstration projects. Support research and infrastructure design as well as integrating BPA data streams to the system. Integrate BPA operating units for policy and standards development, resource planning, wind integration, and coordination with DR programs.

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Protection of load voltage, and sufficiency safety-nets and transformer protection for GIC or impending future	BPA PL: Brian Tuck	YES	**TIP 46 - operations real time study process improvement** This project uses the innovative Operations Study Process Improvement environment to investigate options to reduce unnecessary risks and curtailments by accurately modeling near term system conditions for Operations study engineers following an unplanned outage or during extreme operating conditions. The study automation system will be designed to assist BPA Systems Operations engineers to calculate a reliable system Operating Limit (SOL) for real time operation of BPA's critical transmission paths such as the California Oregon Intertie (COI). The system will be built around PowerWorld's Simulator power flow that is used daily for off-line studies. Key Results/Conclusions ▪ Implemented distributed processing to use multiple CPUs to speed up system operating limit studies by up to 1000%. ▪ Improved the software efficiency of the automated system operating limit studies adding an additional 600% speed improvement. ▪ State estimator and custom software automatically generate 100 cases a day. ▪ State estimator based studies use real measurements for more accurate system studies. ▪ Implemented a power circuit breaker oriented power flow model to find hidden problems. ▪ Cost savings during unplanned line outage events impacting the northern intertie path (±$665K) and west of Cascades north path (±$793K).
Protection of load voltage, and sufficiency safety-nets and transformer protection for GIC or impending future	PSERC PL: Lang Tong (Cornell University)	NO	**Impact of Bad Data and Cyber Data Attack on Electricity Market Operation (M-27)** This project investigates impacts of bad or malicious data on economic dispatch. Specifically, the project studies changes in price and economic dispatch due to state estimation errors caused by meter malfunction, topological errors, and maliciously injected data by adversaries. The research develops ways of detecting bad/malicious data and investigates worst case attack strategies by adversaries with different access capabilities.
Protection of load voltage, and sufficiency safety-nets and transformer protection for GIC or impending future using the synchrophasor technology	PSERC PL: Anurag K Srivastava (Washington State University)	NO	**Testing and Validation of Phasor Measurement Based Devices and Algorithms (S-45)** The electric power system is moving towards the Smart Grid (SG) development for improved reliable, secure and economic operation. Implementation of such a system requires enhanced testing and validation of smart grid technologies as well as development of new approaches to fully utilize the capabilities of these technologies. This project is focused on testing and validation of phasor based applications, testing of devices using existing real time hardware-in-the-loop digital simulation testbed, and development of new applications of phasor data. Specifically, testing of PMU based voltage stability and state estimation algorithms will be performed in real time; a new protection approach will be developed and demonstrated for dynamic protection of transformers and it will be compared to conventional protection schemes. Comparative testing and analysis of PMU, PDC, and historians will be performed using existing and enhanced testbed.

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Protection of load voltage, and sufficiency safety-nets and transformer protection for GIC or impending future using the synchrophasor technology	PSERC PL Vijay Vittal (Arizona State)	**NO**	**Data Mining to Characterize Signatures of Impending System Events or Performance from PMU Measurements (S-44)** This project applies data mining techniques to characterize signatures of impending system events or performance from PMU measurements. The project will evaluate available data mining tools and analyze the ability of these tools to characterize signatures of impending systems events or detrimental system behavior. The use of PMU measurements from multiple locations will also be considered. The performance of the data mining tools will be verified by comparing the results obtained for measurements corresponding to know events on the system.
Utilization of the synchrophasor technology	PSERC PL Mladen Kezunovic (Texas A&M University)	**NO**	**Verifying Interoperability and Application Performance of PMUs and PMU-Enabled IEDs at the Device and System Level (T-43)** As a result of the American Recovery and Reinvestment Act (ARRA) funding and other unrelated infrastructure investment plans in the utility business it is expected that the number of installed Phasor Measurement Units (PMUs) and PMU-enabled Intelligent Electronic Devices (IEDs) will dramatically increase. New applications using synchronized data will become an important part of the overall power system operation. The risk of using such elaborate high precision measurement infrastructure requires appropriate testing for interoperability and application performance at both the device and system level to ensure accuracy and consistency across multiple IED types, as well as future scalability and upgradeability, hence avoiding the costly infrastructure becoming a stranded asset.
Sense power system oscillation modes (0.25-0.8 Hz), and mitigate with new oscillation damping equipment	Sandia National Laboratories	**YES**	**TIP 289 - Wide Area Damping Control Proof-of-Concept Demonstration** Recent efforts by the Bonneville Power Administration (BPA) have identified control schemes that can mitigate inter-area power oscillations through increased damping. This project includes the frequency sensor specifications, the communications link specifications, actuation device specifications, and the design of the high level supervisory control system that monitors system damping and identifies potential failures of the damping control system and takes autonomous corrective action. The goal of this research and development effort is to perform a proof-of-concept demonstration of a wide area damping controller system. Deliverables: ▪ Sandia will furnish prototype frequency sensor devices (e.g. PMU's with updated firmware) to be deployed in the BPA fiber network. These devices will become BPA property upon conclusion of the contract. ▪ Sandia will furnish a damping control node consisting of an energy storage device, power electronics, a computer control system, and a supervisory control system to be installed at the Ross Complex Energy Storage Test Facility. This hardware will become BPA property upon conclusion of the contract. ▪ Sandia and Montana Tech will provide BPA with all software developed under this effort. This includes analysis code developed for PSLF or MATLAB, as well as all control code that runs on the local or supervisory control nodes. ▪ Sandia will provide BPA electronic copies of all reports, workshop briefings, conference papers, journal papers, test plans, drawings, and test data developed under this effort.

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Manage RAS-initiated responses to system disturbances Minimize excessive RAS generation drop	Hitachi America, Ltd.	**YES**	**TIP 275 - New remedial action scheme (RAS) research work to avoid cascading caused by intermittent output of renewable energy resources** The objective of this project is to develop feasible new remedial action schemes (RAS) using synchrophasors and on-line contingency analysis will be studied. Concept of desired RAS is identified. Deliverables: ▪ Syncrophasor data analysis - Issue list and simulation research plan. ▪ Simulation research - Transient stability study for each case ▪ Developing concept of desired RAS - Final report.
Utilization of the synchrophasor technology	PSERC	**NO**	**Real Time PMU-Based Stability Monitoring (S-50)** We propose new algorithms for real time stability monitoring in a control center environment. Two distinct but complementary methods are proposed for PMU-based stability monitoring: (a) waveform analysis to extract the “trending” information of system dynamics embedded in Lyapunov exponents – Is the system approaching instability?, and (b) a real time stability analysis based on energy functions for a faulted system – Will the system remain stable following the fault?. The combination of these approaches will provide a comprehensive and predictive stability monitoring system that help to avoid cascading failures and maximize system reliability.

IV. Transmission Scheduling

Shorter Duration Scheduling Roadmap

Business and Technology Challenges

There are four major challenges in short duration scheduling of transmission: 1) Forecasting transmission flows in near-term, 2) Sub-hour scheduling and integration of ancillary energy markets, 3) Difficulty in accommodating variability in demand and supply, and 4) Potential formation of region-wide energy imbalance market.

Transmission network flows are currently not calculated or predicted, even in one hour in the future. This leaves dispatch in a vulnerable situation, often waiting until the ramp is over to see how things settle out. Also, BPA is moving to ½ hour scheduling. Proposed energy imbalance markets will present challenges to integrating operationally into BPA if they move to 15 or 10 min. markets. Another critical challenge is current scheduling and dispatch systems have difficulty in accommodating variability in demand and supply. Finally, WECC and regional entities are considering formation of an energy imbalance market that would change BPA system operations and require interface with a new independent market.

Specific operational challenges include:

- Integration of dispatch, transmission scheduling & hydro scheduling: Closer coordination with scheduling, hydro power operations and transmission dispatch would provide better understanding of power system impacts of each other's demands and solutions.
- Dispachable renewable resources: Additionally, the system is currently designed for dispatchable resources, but is required to balance increasing amounts of intermittent resources. The current system cannot be scheduled in an open, flexible, and continuous way.

Therefore, an accurate understanding of the sustainable capacity and energy of within–the-hour resources is needed. The understanding would include: how resources are modeled and at what time scale? What are the requirements for monitoring performance, dispatch protocols and extreme events confidence? There is also a need for understanding and acceptance of VGM (Variable Generation Mitigation) and systems and protocols that support open, flexible, and continuous scheduling.

The following are specific capabilities needed:

- Forecast of VGM Events: Curtail projects only when needed to minimize outage duration.
- Continuously variable start/stop time, scheduling interval, ramp rates at any time

R&D Gaps

Business and Technological Challenges which are not addressed by existing R&D programs:

1. Systems and protocols that support open, flexible, and continuous scheduling
2. Forecast of VGM Events
3. Continuously variable start/stop time, scheduling interval, ramp rates at any time

Business and Technological Challenges which are covered partially by existing R&D programs but still require further research and development:

1. Accurate understanding of the sustainable capacity and energy of within–the-hour resources
2. Difficulty in accommodating variability in demand and supply
3. The current system cannot be scheduled in an open, flexible, and continuous way

Business and Technological Challenges which are covered by commercialized technologies and products, however demonstration or confirmation studies may be required:

- None

IV. Transmission Scheduling

IV-1. Shorter Duration Scheduling Technology Roadmap

BPA Transmission Technology Roadmap

Time	2012 – 2015

Business Challenges (BC)

BC 1 Forecasting Transmission Flows in Near-Term (0-3 hours)
Transmission network flows are currently not calculated or predicted even one hour in the future. This leaves dispatch in a vulnerable situation, often waiting until the ramp is over to see how things settle out. (S)

BC 2 Sub Hour Scheduling, Integration of Ancillary Energy Markets (EDT/EIM)
BPA has moved to ½ hour scheduling. Proposed energy imbalance markets will present challenges to integrating operationally into BPA if they move to 15 or 10 min. markets. (M)

BC3 Current scheduling and dispatch systems have difficulty in accommodating variability in demand and supply

BC4 Potential Formation of Region-wide Energy Imbalance Market
WECC and regional entities are considering formation of an energy imbalance market that would change BPA system operations and require interface with a new independent market. (L)

Operational Challenges (OC)

OC 1 Integration of Dispatch, Transmission Scheduling & Hydro Scheduling
Need better and closer coordination with Scheduling, Hydro Power Ops and Tx Dispatch. Better understanding of power system impacts each others demands and solutions.

OC 2 Dispatchable vs. Intermittent Resources
System is currently designed for dispatchable resources, but is required to balance increasing intermittent resources.

OC3 The current system cannot schedule in open, flexible, and continuous way

Operational & Technical Needs (ND)

ND 1 Accurate Understanding of Sustainable Capacity and Energy of within the Hour Resources.
How modeled at what time scale?, What are the requirements?, Monitoring performance, Dispatch protocols and extreme events confidence.

ND 2 Environmental Redispatch
Understanding and acceptance of ER (Environmental Redispatch).

ND3 Systems and protocols to support open, flexible, and continuous scheduling

Required Capabilities (RC)

RC3 Continuously variable start/stop time, scheduling interval, ramp rates at any time

RC 1 Acceptance of ER
Make contracts more clear and protective to avoid fines and customer complaints.

RC 2 Forecast of ER Events
Curtail projects only when needed to minimize outage duration.

Technologies (T)

R&D Programs (RD)

EPRI: Bulk Power System Integration of Variable Generation - Program 173 (2009-2011)

EPRI: Grid Planning - Program 40 (2011)

Business Challenge | Operational Challenge | Operational & Technical Need | Required Capability | Technologies | Existing R&D Programs | Non-Existing R&D Programs (Gaps)

Related Internal and External Projects

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Difficulty in accommodating variability in demand and supply, and potential formation of region-wide energy imbalance market	EPRI	**NO**	**Bulk Power System Integration of Variable Generation - Program 173 (2009-2011)** EPRI research and development in the area of bulk power system integration of variable generation and controllable load will produce knowledge and tools that will help system operators and planners: - Understand the impacts of variable generation and controllable load on system reliability - Control variable generation and controllable load to minimize operational risks - Design robust transmission systems to integrate variable generation and controllable load - Develop system and industry standards that ensure efficient and reliable operation. P173.003 Grid Performance and Modeling of Variable Generation and Evolving Power System Resources P173.005 Operator Tools for Scheduling, Reserve Determination, and Frequency Control with Variable Generation P173.006 Advanced Planning Tools to Study the Impact of Variable Generation and Controllable Loads P173.007 Evaluation of Potential Bulk System Reliability Impacts of Distributed Resources and Potential Mitigating Strategies
The current system cannot schedule in open, flexible, and continuous way for increasing amounts of intermittent resources	EPRI	**NO**	**Grid Planning - Program 40 (2011)** Utilities, transmission companies, and ISOs/RTOs need to plan for future demand growth and provide transmission services for changing generation portfolios. The challenge of meeting reliability requirements with the addition of variable generation and allowing demand response as a capacity resource may necessitate transmission planning to reassess planning objectives. Planning for peak load scenarios may not be sufficient. Evaluation of additional scenarios such as low load and shoulder load, as well as intermittent availability of variable resources, may also be required. Variable resources have two other characteristics that need to be addressed in planning: uncertainty, and a regional nature beyond the traditional utility boundaries. A second focus of this program is to identify and develop solutions and decision-support tools for planners to deal with specific technology gaps to improve overall planning activities. Some projects within the Grid Planning program use phasor measurement to verify models—the foundation for all simulation and analysis efforts—and move traditionally offline analysis tasks closer to online real-time analysis.
The current system cannot schedule in open, flexible, and continuous way for increasing amounts of intermittent resources	Frank Wolak, Stephen Boyd and Mark Thurber, (Stanford Universit)	**NO**	**Reducing the Regulatory Barriers to a Transmission Network That Facilitates Renewable Energy Deployment in a Wholesale Market Regime** The research proposed here will develop a quantitative model that seeks to fill these gaps-specifically for the case of the transmission upgrades in the Western Electricity Coordinating Council (WECC). The model can also serve as a tool for analyzing how various policies, including those aimed at reducing CO_2 emissions, will affect the optimal configuration of a transmission network. We will complement the quantitative model with qualitative case studies of the transmission planning processes in all of the major US electricity markets.

Wind Generation Scheduling

Business and Technology Challenges

The scale of wind power developments demands that wind generation facilities be able to exert effective control capability in response to grid requirements such as primary speed-power control, primary voltage control, secondary voltage control and reactive power management. In addition, communication is another business challenge in wind power plant control. This requires a mechanism for communicating quick reaction commands enabled by new data sets provided by PMUs.

Operational challenges in wind power plant control include:

- Oscillation frequency is drifting lower due to greater inertia on the system.
- PMU data cannot be fully used because State estimator runs once per minute.
- Insufficient reactive control: Conventional methodologies and study tools may not be sufficient or fast enough to accurately initiate the type of reactive control currently deployed or may require accurate system models to be effective.
- Reactive power assignment: Enable stable and equitable reactive power assignment across multiple plants in a hub
- Sub-synchronous frequency control interaction and resonance: Understand risk of sub-synchronous control interactions and oscillation resonance
- Spinning & operating reserves: Balancing Authority ancillary services obligations for wind generators are being filled by other generators on the system.
- Stressed system: Operating the system in stressed conditions increases the probability of severe contingencies or chains of contingencies that are not considered in traditional system security assessment.
- Track Wind Performance for Voltage Control

Operational and technical needs related to those challenges are:

- To improve the system control performance characteristics, maintain system reliability, and minimize expenses related to the system balancing functions, it is necessary to incorporate predicted uncertainty ranges of wind production and load forecasts into the scheduling and load following processes.
- All parties need to use the same forecasts or the same consistent data for their forecasts.
- Need for better or more open pricing of variations from generation schedules.
- Need for better, more accurate forecasts of wind.
- Need to understand and identify ramping capabilities of balancing resources.
- Need to be able to factor in balancing resource characteristics into optimization algorithms specific to conditions and resources in the Pacific Northwest for optimal dispatch.

- Advanced Forecasting and Monitoring Tools - Advanced tools are needed to monitor rapid changes in wind resources in the near-term horizon (current time to hour +3) in order to allow system operators and planners to position balancing resources in the best position to provide balancing services while maintaining very high likelihood of meeting other system operational objectives.

R&D Gaps

Business and Technological Challenges which are not addressed by existing R&D programs:

1. Multi-Scale Wind Generation Scheduling
   - Scheduling for wind depends on device and system behavior at multiple time scales. A critical research need is "Multi-Scale Wind Generation Scheduling". This should include modeling of the device dynamics, the controls, the system control and markets.

Business and Technological Challenges which are covered partially by existing R&D programs but still require further research and development:

1. Scheduling and Load Following Process
2. Optimization algorithms including balancing resource characteristics
3. Analysis Tool or Study for Location of New Weather Equipments
4. Wind Power and Awareness Display Tools

Business and Technological Challenges which are covered by commercialized technologies and products, however demonstration or confirmation studies may be required:

- None

IV-2. Wind Generation Scheduling

Time | **NEW** | **2013 – 2016**

Business Challenges (BC)

BC2 Incentives are not in place to encourage wind generators to schedule according to consistent and accurate forecasts

BC3 Reduce Uncertainty of Wind Power Production
By the nature of variable generation resources, they can result in rapid and significant changes in output, requiring balancing resources to respond in kind.

BC1 Reliably integrate the region's renewable resource

Operational Challenges (OC)

OC3 Forecast Error
Error in wind speed and power factors lead to uncertainty in total wind power production. [BC3]

OC1 Scheduling Error
Actual load and intermittent generation can deviate substantially from their schedules. [BC2, BC3]

OC2 Balancing Resource Value
Value of balancing resources for variations from generation schedules is unclear. BC2, BC3]

OC4 Geographic Diversity
Take advantage of geographic diversity to better integrate wind.
[BC1, BC3]

Operational & Technical Needs (ND)

ND1 Improve System Control Performance
To improve the system control performance characteristics, maintain system reliability, and minimize expenses related to the system balancing functions, it is necessary to incorporate predicted uncertainty ranges of wind production and load forecasts into the scheduling and load following processes
[OC1, OC2]

ND2 Consistent Forecast Data:
All parties need to use the same forecasts or the same consistent data for their forecasts. [OC1,OC3]

ND5 Ramping Capabilities
Need to understand and identify ramping capabilities of balancing resources. [OC2, OC3]

ND3 Pricing Schedule Variation: Need for better or more open pricing of variations from generation schedules [OC2]

ND4 Balancing Resource Optimization: Need to be able to factor in balancing resource characteristics into optimization algorithms specific to conditions and resources in the Pacific Northwest for optimal dispatch. [OC2]

ND7 Advanced Forecasting and Monitoring Tools
Advanced tools are needed to monitor rapid changes in wind resources in the near-term horizon (current time to hour +3) in order to allow system operators and planners to position balancing resources in the best position to provide balancing services while maintaining very high likelihood of meeting other system operational objectives. [OC1, OC2, OC3]

ND6 Identify Geographic Locations
Identify geographic locations with complementary weather patterns for wind farm development. [OC4]

Required Capabilities (RC)

RC1 Improve Scheduling Processes: Scheduling and load following processes that are capable of using a range of wind uncertainty and forecasts [ND1]

RC2 Common system modeling with compatible database. [ND2]

RC3 Balancing Resource Characteristics: Identify characteristics of balancing resources including ramping capabilities, and develop a practical process enabling open pricing [ND3, ND4, ND5]

RC4 Transmission Access
Potential locations need access to transmission corridors and not contribute to congestion. [ND6]

RC5 Optimal Positioning of Weather Observation Equipment
The determination and recommendation of optimal locations in the region for the placement of real-time weather observational instrumentation that supports wind power forecasting and situation awareness efforts. [ND7]

RC6 Optimum Types of Equipment
The determination and recommendation of the optimum type of instrumentation to be installed, be it Anemometers, LIDAR, SODAR or other technologies. [ND7]

RC7 Wind Forecast Display Design
The novel, efficient and effective design and layout of wind power forecasting and situational awareness displays for real-time and planning operational decisions. [ND7]

Technologies (T)

T2 Accurate Wind Forecasting Model with Common Database. [RC1, RC2]

T1 Improved Scheduling and Load Following Process [RC1]

T3 Optimization algorithms including balancing resource characteristics. [RC3]

T4 Analysis Tool or Study for Optimal Location of New Weather Equipment. [RC5, RC6]

T5 Wind Power and Awareness Display Tools. [RC7]

R&D Programs (RD)

Reducing the Regulatory Barriers to a Transmission Network That Facilitates Renewable Energy Deployment in a Wholesale Market Regime
Frank Wolak, Stephen Boyd and Mark Thurber, Stanford University

Catching Wind by the Tail Improving Intermittent Power Operations with Sensing, Statistics and Control
Ram Rajagopal, Stanford University

BPA TIP 256 - EPRI 40.019 Strategic and Flexible Transmission Planning (TRL-5)

Look-Ahead Coordination of Variable Resources for Providing Electric Energy and Regulation Services
Dr. Le Xie, Texas A&M

Integration of Storage Devices into Power Systems with Renewable Energy Sources (S-40), PSERC

Scheduling for wind depends on device and system behavior at multiple time scales. A critical research need is "Multi-Scale Wind Generation Scheduling". This should include modeling of the device dynamics, the controls, the system control and markets.

Legend: Business Challenge | Operational Challenge | Operational & Technical Need | Required Capability | Technologies | Existing R&D Programs | Non-Existing R&D Programs (Gaps)

Related Internal and External Projects

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Balancing Authority ancillary services obligations for wind generators are being filled by other generators on the system.	EPRI BPA PM: Stan Williams Anders Johnson	**YES**	**TIP 256 - EPRI 40.019 Strategic and Flexible Transmission Planning** This project will continue work done in 2011 in P40.019 in two related areas. The first is transmission planning, which considers both economic and reliability aspects in one process and the evaluation of system flexibility to respond to increased ramps in demand caused by an increase in variable generation. This will include ensuring that transmission is considered in measuring flexibility adequacy and the ability of newer resources such as demand response and storage to offer flexibility. Flexibility metrics will be proposed so that they can be adopted by bodies such as NERC to ensure flexibility adequacy in systems aiming for high penetrations of VG. Case studies will be extended from 2011 work to show the need (or otherwise) of such a metric. Deliverables: ▪ Metrics to determine the flexibility needs and resources in a system, considering new and existing flexibility resources as well as the transmission network in a system ▪ Results from case studies that show the need to consider balancing reliability and economics and improvements that can be made by using the framework developed. ▪ Identification of the proper consideration of flexibility in system resource planning by using case studies to show the value of flexibility ▪ A better understanding of the flexibility offered by demand response and how this compares with other flexible resources in managing variability and uncertainty
Balancing Authority ancillary services obligations for wind generators are being filled by other generators on the system.	Stanford University PL: Ram Rajagopal,	**NO**	**Catching Wind by the Tail Improving Intermittent Power Operations with Sensing, Statistics and Control** The project seeks approaches to increase the penetration of wind energy production by decreasing the planning, safety and operating costs due to wind uncertainty for system operators, large farm operators and small local generation operators.
Balancing Authority ancillary services obligations for wind generators are being filled by other generators on the system.	Texas A&M University PL: Le Xie	**NO**	**Look-Ahead Coordination of Variable Resources for Providing Electric Energy and Regulation Services** The objective of Xie's research is to investigate a novel look-ahead operating paradigm which enables the participation of variable energy resources such as wind and solar power in both energy balancing and a variety of ancillary services, which are necessary for reliable operations in power grid.

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Balancing Authority ancillary services obligations for wind generators are being filled by other generators on the system.	PSERC	**NO**	**Integration of Storage Devices into Power Systems with Renewable Energy Sources (S-40)** The recent advances in the state of the art of storage technology have led to wider deployment of storage technologies. This project will develop models and a simulation methodology for analyzing the effects of storage integration on transmission constrained electricity markets over longer-term periods. Our goal is to assess the use of storage as a system resource that provides the flexibility to mitigate the effects of variable renewable energy sources, improves the overall system reliability, and has the ability to provide energy- and capacity-based ancillary services. The methodology can be implemented into practical tools to quantify the system variable effects.

Outage Management Roadmap

Business and Technology Challenges

Another critical challenge in Transmission Scheduling is Outage Management. System constraints and growing demand make attaining outages difficult. The current outage management system is not well coordinated. The critical challenge is to maintain and improve the physical grid while delivering the transmission services and capacity that our customers need.

Specific challenges include**:**

- Increased pressure to replace equipment 'Hot' (without an outage)
- Increased difficulty to take outages on power system equipment and lines: Insufficient capacity and increasing demand reduces planned outage windows
- Optimal outage management: The current practices do not allow optimal outage management of the transmission system in terms of low cost and reliability. Outage season has been reduced to just 2 months, October and November to accomplish 12 months of work.

Therefore, a work management system is needed that will schedule maintenance work, outage balance, labor, and consolidate locations. The system should upload and download specifications and standards, provision all necessary parts and supplies (inventory rig), update labor times to work order system, and restack the schedule if necessary.

Additional needs include: an outage management coordination system to integrate proposed outages (DART), power flow, PUF tables, into a simple tool for Outage Dispatchers to assess impact of proposed outages before they are approved. It should also collect outage information from other utilities that impact BPA transmission. SYS OPS power flow study engineers and others need access too. We also need the ability to perform more system maintenance without outages.

A required capability would be the ability to check combinations of outages, against impact to transmission path flows and system operating limits without performing a full study.

R&D Gaps

Business and Technological Challenges which are not addressed by existing R&D programs:

1. Integrate proposed outages (DART), power flow, PUF tables, into a simple tool for Outage Dispatchers to assess impact of proposed outages
2. Optimal outage management

Business and Technological Challenges which are covered partially by existing R&D programs but still require further research and development:

1. Increased difficulty in taking outages on power system equipment and lines

Business and Technological Challenges which are covered by commercialized technologies and products, however demonstration or confirmation studies may be required:

- None

IV-3. Outage Management Technology Roadmap

Time: 2012 – 2015

Business Challenges (BC)

BC1 Preserve Transmission Capacity Inventory while Maintaining the Grid
System constraints and growing demand make attaining outages difficult. (S/M/L)

BC2 Outage Management Coordination
Lack of outage management and coordination. (M)

Operational Challenges (OC)

OC 1 Outage Constraints
a) Increased pressure to replace equipment 'Hot' (without an outage), b) Pressure to minimize outage windows – complete work in shorter timeframe than desired, and c) Increased difficulty to take outages on power system equipment and lines. **(S)**

OC 2 Optimization model
The current practice cannot allow optimal outage management of the transmission system regarding low cost and reliability. Outage season has reduced to just 2 months October and November for 12 months of work (S)

Operational & Technical Needs (ND)

ND1 Work Management System
Schedule Maintenance work, Outage Balance, labor, Schedule consolidating locations. Upload/download necessary specifications and standards. Provision all necessary parts and supplies (inventory rig). Update labor times to WO System. Restack schedule if necessary

ND2 Outage Management Coordination
Develop a simple system to integrate proposed outages (DART), power flow, PUF tables, into a simple system for Outage Dispatchers to assess impact of proposed outages before they are approved. Also collect outage from other utilities that impact BPA transmission. SYS OPS power flow study engineers and others need access too.

ND3 Ability to Perform more System Maintenance without Outages

ND4 Forecasting Conditions for Outage Periods

Required Capabilities (RC)

RC1: check combinations of outages, against impact to transmission path flows and system operating limits without performing a full study.

Technologies (T)

R&D Programs (RD)

BERKELY (DR. OREN): Optimization through transmission switching

Legend: Business Challenge | Operational Challenge | Operational & Technical Need | Required Capability | Technologies | Existing R&D Programs | Non-Existing R&D Programs (Gaps)

Related Internal and External Projects

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Increased pressure to replace equipment 'Hot' (without an outage), and increased difficulty to take outages on power system equipment and lines because of insufficient capacity and increasing demand.	University of California, Berkeley PL: Shmuel Oren	**NO**	**1. Ongoing Research** Optimization through transmission switching Ref: Hedman, Kory W., Richard P. O'Neill, Emily Bartholomew Fisher, and Shmuel S. **Oren**, "Optimal Transmission Switching - Sensitivity Analysis and Extensions," IEEE Transactions on Power Systems , Vol. 23, No. 3, (2008) pp 1469-1479. Hedman, Kory W., Richard O'Neill, Emily Bartholomew Fisher, and Shmuel S. **Oren**, "Optimal Transmission Switching with Contingency Analysis", IEEE Transactions on Power Systems , Vol. 24, No. 3, (2009) pp 1577-1586.

Congestion Management Roadmap

Business and Technology Challenges

Congestion management is another critical challenge in transmission scheduling. Generally, the challenge is to reduce congestion by increasing capacity of the transmission system without extensive capital investment.

Specific challenges for BPA are:

- Difficulty in identifying drivers for congestion and determining congestion costs for expansion planning purposes given the increases in wind generation, changes in system operating limits, a potential Energy Imbalance Market, and possible new energy storage and demand response resources.
- Increasing transmission congestion on the FCRTS requires system operations to become proactive in identifying and managing congestion.

To address those challenges we need to:

- Provide alternatives to curtailment
- Use power flow controls on critical circuits to manage congestion
- Develop day-ahead and hour-ahead forecasting of congestion
- Develop the ability to assess path capacity in near time or real time: It is estimated that the daily average capacity grid utilization rates are typically only 40% to 60% of theoretical capacity. Some of this unused capacity could be recovered through peak shifting.

Capabilities needed to meet those challenges include:

- Improved tools for running studies in real-time, including static and dynamic security assessment.
- Better forecasting tools for load, generation, and line temperatures. A supporting technology would be line temperature monitoring that could indicate line capacity utilization and help determine which lines can be taken out for maintenance work and load optimization.
- New power electronic devices that would enable dispatchers to control power flows more directly.
- Demand response: Peak shifting would require transitive signals to enable devices to increase electricity use during low demand periods and decrease electricity use in high demand periods.

R&D Gaps

Business and Technological Challenges which are not addressed by existing R&D programs:

1. Develop the ability to assess/forecast path capacity/congestion in near time or real time
2. Ability to make available all real time transmission capacity

Business and Technological Challenges which are covered partially by existing R&D programs but still require further research and development:

1. Power flow controls on critical circuits to manage congestion
2. Improved tools for running studies in real-time, including static and dynamic security assessment
3. Better forecasting tools for load, generation, and line temperatures.
4. New power electronic devices that would enable dispatchers to control power flows more directly.
5. Demand response

Business and Technological Challenges which are covered by commercialized technologies and products, however demonstration or confirmation studies may be required:

- None

IV-3. Congestion Management Technology Roadmap

Time: 2012 – 2015

Business Challenges (BC)

BC1 Transmission System Capacity
Increase capacity of the transmission system without extensive capital investment.

Operational Challenges (OC)

OC1 Forecasting Drivers for Congestion & Congestion Costs
BPA has difficulty in identifying drivers for congestion and determining congestion costs for expansion planning purposes given the increases in wind generation, changes in system operations (SOL, EIM) and new storage and DR resources.

OC2 Increasing Transmission Congestion
Increasing transmission congestion on the FCRTS requires System Operations to become proactive in identifying and managing congestion.

Operational & Technical Needs (ND)

ND1 Provide Alternatives to Curtailment

ND2 Power flow controls on critical circuits to manage congestion

ND3 Day-ahead and hour-ahead forecasting of congestion

ND4 Need to be able to assess path capacity in near time or real time

ND Peak Shifting
It is estimated that the daily average capacity grid utilization rates are typically only 40% to 60% of theoretical capacity. Some of this unused capacity could be recovered through peak shifting

Required Capabilities (RC)

RC1 Improved tools for running studies in real-time, including static and dynamic security assessment;

RC2 Better forecasting tools for load, generation, and line temperatures

RC3 New power electronic devices that would enable dispatchers to control power flows more directly.

RC Demand Response
Peak shifting would require transactive signals to enable devices to increase electricity use during low demand periods and decrease electricity use in high demand periods.

Technologies (T)

T1: Monitor Line Temperature
Monitor line temperature with increasing capacity.
- Determine what lines can be taken out for work and optimize load.

R&D Programs (RD)

- BPA TIP 244: Advanced life extending control of multiple energy storage solutions (TIP-4)
- PSERC: Next Generation On-Line Dynamic Security Assessment (S-38)
- PSERC: Quantifying Benefits of Demand Response and Look-ahead Dispatch in Support of Variable Resources (M-26)
- ARPA-E: Highly Dispatchable and Distributed Demand Response for the Integration of Distributed Generation
- PSERC: Coupling Wind Generation with Controllable Load and Storage: A Time-Series Application of the SuperOPF (M-22)
- PSERC: Design and Valuation Design and Valuation of Demand Response Mechanisms and Instruments for Integrating Renewable Generation Resources in a Smart Grid Environment (M-23)
- ARPA-E: Transmission Topology Control for Infrastructure Resilience to the Integration of Renewable Generation
- PSERC: Tools and Techniques for Considering Transmission Corridor Options to Accommodate Large Scale Renewable Energy Resources (S-41)

Business Challenge | Operational Challenge | Operational & Technical Need | Required Capability | Technologies | Existing R&D Programs | Non-Existing R&D Programs (Gaps)

Related Internal and External Projects

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
BPA has difficulty in identifying drivers for congestion and determining congestion costs for expansion planning purposes given the increases in wind generation, changes in system operations (SOL, EIM) and new storage and DR resources.	BPA PL: Stephen White	**YES**	**TIP 244 - Advanced Life Extending Control of Multiple Energy Storage Solutions** This project includes advanced "life extending control" and coordination of multiple energy storage solutions to maximize cost effective energy production, reduce dependency and strain on the hydro-power system by buffering from variable renewables, reduce spinning reserve and peak load problems, increase transmission capacity and help stabilize power quality disturbances. Key Results/Conclusions: The OSU WESRF in-lab grid, established through BPA funding, significantly benefits controller development while enabling hardware verification. The in-lab grid features an emulated wind farm, energy storage systems (supercapacitors, flow cell battery, and pumped hydro), traditional hydro generation resources, and local loads. These models show the promise of significant contributions to life extending control (LEC) algorithms that can integrate RDI models and dispatch resources, including energy storage resources, in a manner that would optimize hydro performance and overall system economics. It was also demonstrated that transmission congestion can be alleviated by adding energy storage devices and demand response loads to key locations on the grid.
BPA has difficulty in identifying drivers for congestion and determining congestion costs for expansion planning purposes given DR resource	ARPA-E AutoGrid, Inc.	**NO**	**Highly Dispatchable and Distributed Demand Response for the Integration of Distributed Generation** AutoGrid, Inc., in conjunction with Lawrence Berkeley National Lab and Columbia University, will design and demonstrate a highly distributed Demand Response Optimization and Management System for Real-Time (DROMS-RT). The project will enable "personalized" price signals to be sent to millions of customers in extremely short timeframes. This will allow customers to reduce their demand when the grid is congested. DROMS-RT is expected to provide a 90% reduction in the cost of operating demand response programs in the United States.
Improved tools for running studies in real-time, including static and dynamic security assessment	ARPA-E Charles River Associates	**NO**	**Transmission Topology Control for Infrastructure Resilience to the Integration of Renewable Generation** Charles River Associates will develop decision support technology that will improve the efficiency of the electrical grid by implementing appropriate short term changes of transmission line status, i.e., by controlling the configuration of the transmission grid. The changes will relieve transmission congestion, as well as provide additional tools and controls to operators to manage uncertainty, thus enabling higher levels of renewable generation.

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Need Improved tools for running studies in real-time, including static and dynamic security assessment	PSERC PL: Vijay Vittal (Arizona State University)	**NO**	**Next Generation On-Line Dynamic Security Assessment (S-38)** This project addresses five elemental aspects of analysis for the enhanced performance of on-line dynamic security assessment. These five elemental components includes; a) A systematic process to determine the right-sized dynamic equivalent for the phenomenon to be analyzed, b) Employing risk based analysis to select multi-element contingencies, c) Increased processing efficiency in decision-tree training, d) Using efficient trajectory sensitivity methods to evaluate stability for changing system conditions, and e) Efficient determination of the appropriate level of preventive and/or corrective control action to steer the system away from the boundary of insecurity.
Difficulty in identifying drivers for congestion and determining congestion costs for expansion planning purposes given the increases in wind generation, changes in system operations (SOL, EIM) and new storage and DR resources	PSERC PL: Tim Mount (Cornell University)	**NO**	**Coupling Wind Generation with Controllable Load and Storage: A Time-Series Application of the SuperOPF (M-22)** The objective of this project is to evaluate the effects of using controllable load and storage to offset the effects of intermittent wind generation on overall system performance and on the operating costs and revenues for different loads and generators. This task will be accomplished by enhancing the current capabilities of the SuperOPF developed at Cornell to model sequential time periods that capture the effects of daily load cycles and the ability to shift load among time periods.
Difficulty in identifying drivers for congestion and determining congestion costs for expansion planning purposes given the increases in wind generation	PSERC PL: Vijay Vittal (Arizona State University)	**NO**	**Tools and Techniques for Considering Transmission Corridor Options to Accommodate Large Scale Renewable Energy Resources (S-41)** The project develops assessment tools and techniques for considering transmission corridor options to accommodate high levels of penetration of renewable energy resources.

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Difficulty in identifying drivers for congestion and determining congestion costs for expansion planning purposes given the increases in wind generation, changes in system operations (SOL, EIM) and new storage and DR resources	PSERC PL: Le Xie (Texas A&M University)	**NO**	**Quantifying Benefits of Demand Response and Look-ahead Dispatch in Support of Variable Resources (M-26)** The objective of this project is to conduct a first-of-its-kind empirical study on the benefits of combining look-ahead dynamic dispatch with price responsive demands for integration of variable energy resources. Based on substation level demand response data and site-specific wind generation data from ERCOT, this project will develop algorithms and a case study to quantify (1) the price elasticity of demand for typical users, and (2) the economic benefit of look-ahead dispatch with price responsive loads. To our knowledge, this is the first study to estimate demand response at the customer level for a U.S. regional system operator. Moreover, we will combine the look-ahead dispatch with the price responsive demand to quantify the system-wide benefits..
Difficulty in identifying drivers for congestion and determining congestion costs for expansion planning purposes given the increases in wind generation, changes in system operations (SOL, EIM) and new storage and DR resources	PSERC PL: Shi-Jie Deng (Georgia Institute of Technology)	**NO**	**Design and Valuation Design and Valuation of Demand Response Mechanisms and Instruments for Integrating Renewable Generation Resources in a Smart Grid Environment (M-23)** We propose to investigate alternative contractual based approaches to the design and valuation of demand response (DR) mechanisms and instruments aimed at addressing the ancillary service (AS) challenges associated with integrating an increasing quantity of intermittent renewable generation resources into a power grid. For our investigation, we will develop a methodology for simulating systems with integrated renewable and DR resources over longer periods. The methodology will be effectively used to study how different DR mechanisms and financial instruments can facilitate the integration of DR programs into ISO markets and provide the much needed AS support to the intermittent renewable generation.

V. Work Force Enhancement

Work Force Utilization Roadmap

Business and Technology Challenges

The Work-Force Efficiency roadmap includes six business challenges and nearly a dozen operational challenges.

Business Challenges Include:

- Miss-operations and human error in system protection equipments causes for initiating automatic transmission system outages. (NERC Reliability Indicators)
- Workforces systems to help manage workforce schedules
- Workforce has the skills and knowledge to minimize errors that compromise safety system reliability and ability to maximize FCRPS usages and availability
- Maximize skilled workforce, workers must have the skills needed to keep up with technological advances
- Compliance with NERC Standards The new revision of TPL-001-3 Standards will greatly increase the amount of transient stability studies required over a wide range of power system conditions

Operational Challenges Include:

- Workforce scheduling of outages is increasing while windows of opportunity are shortening.
- Human error e.g. inadvertent operations, switching errors, etc….
- Expedite and improve processes to reduce compliance burdens
- Continual studies to review RAS and SPS controls resulting from the Pacific Southwest outage in Sept. 2011
- Increasing need to perform high volume transient stability studies
- Having studies to support operating procedures, such as oscillation damping
- Compliance drifts due to outside distraction & familiarity can lead to lack of attention or focus resulting in errors.
- Increased system complexity and new technologies can lead to increased human error
- A Changing Workforce where employees retire or change positions leaves skill gaps in the organization
- Increasing number of new resources coming online e.g. wind, which may not be as responsive to frequency or voltage as conventional resources.
- Having forecasts of load, generation, and outages early enough to run next day and current day studies

R&D Gaps

Business and Technological Challenges which are not addressed by existing R&D programs:

1. Procedure check
   - Bar codes and readers that prompt and check correct sequence work procedures

Business and Technological Challenges which are covered partially by existing R&D programs but still require further research and development:

1. Smart locks
   - Knowledge management system

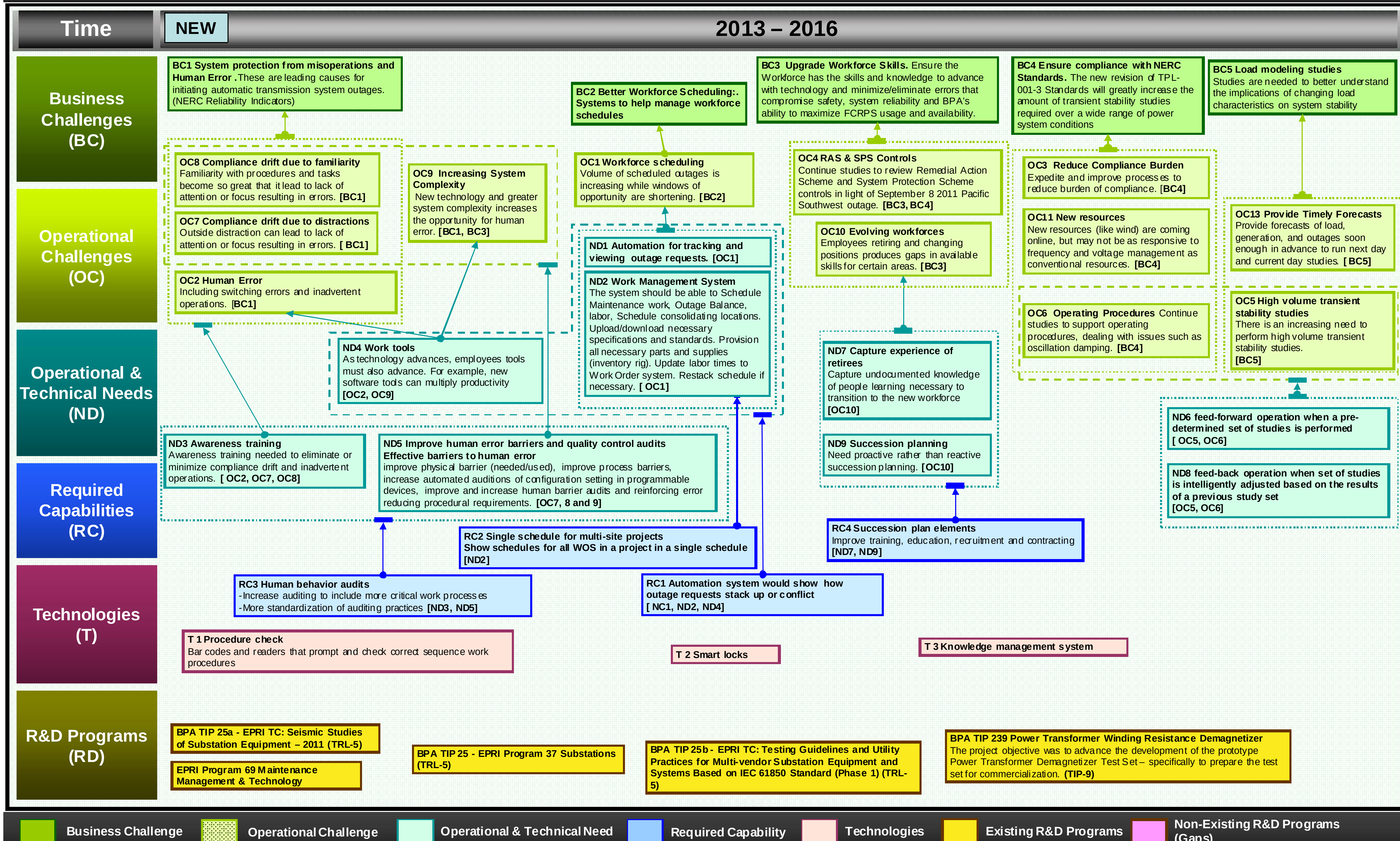
Business and Technological Challenges which are covered by commercialized technologies and products, however demonstration or confirmation studies may be required:

   - None

V. Workforce Enhancement

V-1. Workforce Utilization Technology Roadmap

BPA Transmission Technology Roadmap



Related Internal and External Projects

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Compliance with NERC Standards The new revision of TPL-001-3 Standards will greatly increase the amount of transient stability studies required over a wide range of power system conditions	EPRI BPA PM: Richard Becker 2010 - 2011	**YES**	**TIP 25 - EPRI Program 37 Substations** This EPRI program spans the full breadth of technologies found within both transmission substations & generation switchyards. EPRI's Substations Program offers the most complete portfolio of globally available technologies and tools for utility personnel involved in making strategic and tactical decisions for substation asset utilization and maintenance.
Compliance with NERC Standards The new revision of TPL-001-3 Standards will greatly increase the amount of transient stability studies required over a wide range of power system conditions	EPRI PI: Ashel Schiff BPA PM: Leon Kempner Jr. 2009 - 2012	**YES**	**TIP 25a - EPRI TC: Seismic Studies of Substation Equipment** EPRI will select the item(s) of equipment that is (are) to be tested for each year. EPRI establishes equipment support structure specifications and vibration test requirements, electrical equipment specifications, and test specifications. EPRI will select a vibration testing facility (and electrical testing laboratory, if required) to perform tests and EPRI draws a contract for laboratory services. The manufacturer and the testing laboratory prepare qualification documentation for the equipment that is qualified following IEEE 693 requirements Key Results/Conclusions: - Acceptance Criteria for Qualifying Hollow-Core Composites - Qualifying Components with Complex Geometry, Non-Linear Response, or Non-Measureable Failure Modes - Sine Beat Test Procedure - Table Impulse to Excite Equipment on Shake Table - New Procedure for Qualifying Transformer-Bushing Systems - Orientation of Equipment Modes of Vibration can cause Under- or Over-Testing - Curve Fitting to estimate Damping and Frequency in the Time Domain
Compliance with NERC Standards The new revision of TPL-001-3 Standards will greatly increase the amount of transient stability studies required over a wide range of power system conditions	EPRI BPA PM: Aaron Martin 2011 - 2012	**YES**	**TIP 25b - EPRI TC: Testing Guidelines and Utility Practices for Multi-vendor Substation Equipment and Systems Based on IEC 61850 Standard (Phase 1)** The goal of this project is to research and develop testing guidelines that can be used in field to assist in function and performance testing for multi-vendor equipment and systems based on the IEC 61850 standard Key Results/Conclusions: - Completed the topology design for the testbed system. - Completed the first draft of P&C function design. - Create the interoperability in protection and control systems to effectively prevent vendor “lock-in”. - Provide a standard-based platform to facilitate data integration and information exchange throughout substations and enterprise.

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Workforce has the skills and knowledge to minimize errors that compromise safety system reliability and ability to maximize FCRPS usages and availability	BPA PM: Jeff Hildreth 2011 – 2012	**YES**	**TIP 239: Power Transformer Winding Resistance Demagnetizer** The objective of this project is to prepare the test set for commercialization. Specific tasks include field deployment and evaluation of test sets, securing the intellectual property associated with the invention, and identifying appropriate potential partners who can bring the device to market. Key Results/Conclusions: ▪ Six (6) completed beta prototype field trial units. ▪ Report summarizing the field performance of the beta units. ▪ Patent application (if applicable). ▪ Peer-reviewed publication describing the invention. ▪ Plan for the commercialization of the invention
Workforces systems to help manage workforce schedules Workforce has the skills and knowledge to minimize errors that compromise safety system reliability and ability to maximize FCRPS usages and availability	EPRI	**NO**	**EPRI Program 69 Maintenance Management & Technology** EPRI's Operations and Maintenance programs help members transition to, and sustain, the least-costly procedures and practices associated with plant maintenance. The key attributes of an optimized program are adoption of information management needed to support a condition-based approach to maintenance, and replacement of costly corrective maintenance with proactive preventive maintenance. The focus of this program is on providing an integrated solution that addresses the needs for processes, technologies, and skilled people, which enables condition-based maintenance to support risk-informed maintenance decisions.

VI. Changing Generation Resources

Integration of Variable Resources Roadmap

Business and Technology Challenges

Integration of the variable resources in BPA's balancing area presents challenges to the Federal Columbia River Power System (FCRPS). As large amounts of variable generation such as wind are added to the energy mix in the Pacific Northwest, increasing amounts of flexible dispatchable resources are required to integrate them. The FCRPS is a large flexible resource that is limited by 'higher order' hydro obligations such as fish protection constraints, navigation, irrigation, and recreation. These limitations reduce the system's balancing resources and present challenges to scheduling, voltage stability, frequency control and response, and contribute to transmission constraints. We are thus limited in providing all the ancillary services expected of a balancing authority (BA).

Specific operational challenges include provisioning sufficient balancing reserves through the FCRPS or developing other types of reserves than those currently available; increased wear & tear due to increase operations of power control breakers to switch capacitor banks for voltage control; changes to path flows impacting voltage, voltage stability and system oscillation. These challenges add to transmission constraints and present additional demands to RAS (Remedial Action Schemes) arming.

The required operational and technical needs include frequency response controls; voltage controls; manage variability of renewable generation; increased balancing reserve capacity; reducing balancing reserve requirement; new or better ways to control voltage changes due to variable power flow

Therefore, required technical capabilities to respond to the challenges include:

- Digital emulation of governor response of standard generators
- Analytical model: Modeling capability analyzing how energy storage can impact BPA balancing reserves and the current power & transmission system
- Advanced Dispatch Tools: Dispatch tools should provide situational awareness of wind ramps, consider reserve requirements, and include operator training.
- Increase dynamic transfer capability
    - More robust PCB (power circuit breaker)
    - Capability to accomplish higher duty cycles

R&D Gaps

Business and Technological Challenges which are not addressed by existing R&D programs:

1. Governor control, voltage control and accommodation in the power system due to dynamic power schedules

Business and Technological Challenges which are covered partially by existing R&D programs but still require further research and development:

1. Modeling capability analyzing how energy storage impact BPA balancing reserves
2. Advanced Dispatch Tools
3. Increase dynamic transfer capability
4. More robust PCB (power circuit breaker) to accommodate dynamic transfers

Business and Technological Challenges which are covered by commercialized technologies and products, however demonstration or confirmation studies may be required:

- None

VI-1. Integration of Variable Resources Technology Roadmap

Time: 2012 – 2015

Business Challenges (BC)

BC 1 Grid Integration of Variable Energy Resources
As large amounts of variable generation such as wind and solar are added to the energy mix in the Pacific Northwest, increasing amounts of flexible dispatchable resources are required to integrate them. The FCRPS is a large flexible resource that is limited by 'higher order' hydro obligations like fish constraints, navigation, irrigation, and recreation. These limitations reduce the system's balancing resources and present challenges to scheduling, voltage stability, frequency control and response, and contribute to transmission constraints. (Solar and wind have different characteristics in these areas.). (S/M/L)

Operational Challenges (OC)

OC 1 Lack of Balancing Reserves
More balancing reserves are necessary to integrate increasing amounts of intermittent generation, and at increasing cost.

OC 2 System Changes
Variable generation changes path flows impacting voltage, voltage stability, system oscillation and adds to transmission constraints, and RAS arming challenge.

OC 3 Increased Wear & Tear
Variable generation causes increased wear and tear on equipment due to increase operations of Power Control Breakers to switch caps for voltage control

Operational & Technical Needs (ND)

ND 1 Frequency Response Controls
Need to response to frequency excursion.

ND 2 Voltage Controls
Secondary voltage control to deal with changes in power flows on the system.

ND 3 Manage variability of renewable generation

ND 4 Increased Balancing Reserve Capacity
Need to identify cost effective energy storage solution. (refer ESWG)

ND 5 Reducing balancing reserve requirement

ND6 Need new or better ways to control voltage changes due to variable power flow

Required Capabilities (RC)

RC1 Emulate governor response of standard generators; 5% droop

RC 2 Analytical Model
Modeling capability analyzing how a energy storage impact BPA balancing reserves and current power & transmission system

RC 3 Advanced Dispatch Tools
The dispatch tool should provide situational awareness of wind ramps, consider reserve requirements, and include operator training

RC4 Increase dynamic transfer capability

RC5 More robust PCB (power circuit breaker). Capability to accomplish higher duty cycles.

Technologies (T)

T 1 Short Term Wind Forecasting Techniques
Current techniques are pretty good at predicting wind ramp averages. Techniques that predict actual wind ramps are needed. **Current Research: NREL, 3Tier**

T 2 Advanced Dispatch Tools
Decision Support for Dispatchers

T3 Dynamic Schedules

T4 Automatic arming of RAS

T5 Static VAR Compensators to improve voltage

T6 A technology which accommodates higher duty voltage control RC10

R&D Programs (RD)

- BPA TIP 237 - Bidirectional multipath dynamic transfer analysis (TIP-4)
- BPA TIP 51 - Response based voltage stability controls (TRL-9)
- PSERC: The Smart Grid Needs: Model and Data Interoperability and Unified Generalized State Estimator (S-39)
- ARPA-E: Transformer-less Unified Power Flow Controller for Wind and Solar Power Transmission
- BPA TIP 35 - PNW Smart Grid Demo (TRL-8)
- ARPA-E: Magnetically Pulsed Hybrid Breaker for High-Voltage Direct Current (HVDC) Power Distribution Protection
- PSERC: Integration of Storage Devices into Power Systems with Renewable Energy Sources (S-40)
- BPA TIP 114 - Improved wind energy integration through advanced forecasting and coordination of energy storage systems
- ARPA-E: Improved Power System Operations Using Advanced Stochastic Optimization
- PSERC: Low-Frequency Transmission for Wind Farm Power (S-42)
- Georgia Tech (Grijalva): ARPA-E Green Energy Network Integration. Multi-factor analysis for wind planning and operations
- BPA TIP 244 - Advanced life extending control of multiple energy storage solutions (TIP-4)
- ARPA-E: Energy Positioning: Control and Economics
- EPRI: Grid Planning - Program 40 (2011)
- EPRI: Bulk Power System Integration of Variable Generation - Program 173 (2009-2011)
- ARPA-E: Distributed Power Flow Control Using Smart Wires for Energy Routing
- Tools and Techniques for Considering Transmission Corridor Options to Accommodate Large Scale Renewable Energy Resources (S-41), PSERC
- BPA TIP 260 - A Modular and Dispatchable Battery Storage System (TRL-9)
- BPA TIP 266 - EWEB / Metropolitan Wastewater Management Commission (MWMC) (TRL-9)
- BPA TIP 277 - Data Centers as Demand Response Resources (TRL-8)
- BPA TIP 286 - Energy Storage as a Demand Response Asset at Industrial Facilities and at Critical Points on the Transmission Network to Increase and Decrease Load on Demand (TRL-7)
- Highly Dispatchable and Distributed Demand Response for the Integration of Distributed Generation, ARPA-E
- Coordinated Aggregation of Distributed Demand-Side Resources (S-52), PSERC
- BPA TIP 270 - Demand Response Demonstration Market (TRL-8)
- BPA TIP 285 - Energy Storage: Multifaceted tool for demand management (TRL-8)
- BPA TIP 281 - Impacts Due to Dynamic Transfers (TRL-6)

Legend: Business Challenge | Operational Challenge | Operational & Technical Need | Required Capability | Technologies | Existing R&D Programs | Non-Existing R&D Programs (Gaps)

Related Internal and External Projects

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Lack of balancing reserves - increasing amounts of flexible dispatchable resources are required to integrate renewable energy	BPA PL: Brian Tuck	YES	**TIP 237 - Bidirectional Multipath Dynamic Transfer Analysis** This project is intended to improve the new dynamic transfer methodology for integrating large amounts of intermittent energy sources. This project will evaluate improvements to the methodology, implement prototype tools to study wind integration models (such as the NREL / 3 TIER Western Wind and Solar Integration Study mesoscale model) using the new methodology, and identify approaches to compute additional costs incurred by BPA transmission when accommodating dynamic transfer across the FCRTS. Key Results/Conclusions: Dynamic is a regional concern. BPA and Maxisys worked with the region and developed a common methodology to compute the Variable Transfer Limits. In summary ▪ Developed a non-linear multi-variable optimization algorithm ▪ Built consensus on a regionally acceptable methodology ▪ Utilities tested the new methodology ▪ Solved one of the most complicated problems The relationship between Variable and Static Transfers on paths needs to be analyzed. There are some policy questions to be resolved. They are to determine the a) acceptable magnitude/frequency of voltage deviation, b) acceptable levels of incremental cost due to increased variability and c) acceptable levels of equipment operation due to increased variability. In addition, further studies are needed to determine trade-offs between variable and static transfer. Dynamic Transfer is an emerging issue that has reliability and financial implications for some paths / flowgates and further study is needed.
Analytical model - modeling capability analyzing how an energy storage impact BPA balancing reserves and current power & transmission system	BPA PL: Mike Hulse	YES	**TIP 114 - Improved Wind Energy Integration Through Advanced Forecasting And Coordination of Energy Storage Systems** This research seeks to enable more effective use of energy storage to minimize scheduling uncertainty, increase load leveling capabilities and reduce reserve requirements. This advanced research includes comprehensive simulations and experimental lab-grid implementation that models renewable installations, traditional generation sources, energy storage technologies, power electronic converter control, and representative loads. Key Results/Conclusions: A model of the in-lab grid, including the ZnBr flow cell battery, supercapacitors, and pumped hydro has been developed, including the WESRF dynamometer and Arbitrary Waveform Generator (wind farm). This model includes initial characterization of the capacities and responses of the ZnBr system, the supercapacitors, and the pumped hydro to be modeled. The model also accepts actual wind data as an input. Additionally, an initial version of the energy storage controller has been developed. The model presented here will be used to continue to develop the best control approaches for the three energy storage mediums.

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Analytical model - modeling capability analyzing how an energy storage impact BPA balancing reserves and current power & transmission system	BPA PL: Stephen White	**YES**	**TIP 244 - Advanced Life Extending Control of Multiple Energy Storage Solutions** This project includes advanced "life extending control" and coordination of multiple energy storage solutions to maximize cost effective energy production, reduce dependency and strain on the hydro-power system by buffering from variable renewables, reduce spinning reserve and peak load problems, increase transmission capacity and help stabilize power quality disturbances. Key Results/Conclusions: The OSU WESRF in-lab grid, established through BPA funding, significantly benefits controller development while enabling hardware verification. The in-lab grid features an emulated wind farm, energy storage systems (supercapacitors, flow cell battery, and pumped hydro), traditional hydro generation resources, and local loads. These models show the promise of significant contributions to life extending control (LEC) algorithms that can integrate RDI models and dispatch resources, including energy storage resources, in a manner that would optimize hydro performance and overall system economics. It was also demonstrated that transmission congestion can be alleviated by adding energy storage devices and demand response loads to key locations on the grid.
Analytical model - modeling capability analyzing how an energy storage impact BPA balancing reserves and current power & transmission system	PSERC PL: Project Leader: Mladen Kezunovic (Texas A&M University	**NO**	**The Smart Grid Needs: Model and Data Interoperability and Unified Generalized State Estimator (S-39)** Future Smart Grid applications such as Unified Generalized State Estimation, Intelligent Alarm Processing, and Optimized Fault Location, can benefit from the smart grid integration across data and models but the problem of data and model interoperability hinders the implementation. As an example, two difficult and interrelated problems in state estimation, ability to detect topology errors, and implementation complexity due to the two-model (node/breaker and bus/branch) architecture, will be much easier to solve if data and model interoperability are resolved. This project will identify the interoperability issues and will illustrate novel ways of their resolution in the future so that both legacy solutions, as well as future smart grid applications can utilize the same data and models but use them in a manner consistent with the application requirements and aims.
Analytical model - modeling capability analyzing how an energy storage impact BPA balancing reserves and current power & transmission system	ARPA-E Sandia National Laboratory	**NO**	**Improved Power System Operations Using Advanced Stochastic Optimization** Market management systems (MMSs) are used to securely and optimally determine which energy resources should be used to service energy demand. Increased penetration of renewable energy resources increases the uncertainty of operating and market conditions, complicating decision making. Sandia National Laboratory will collaborate with Iowa State University, the University of California at Davis, Alstom Grid, and ISO New England to create probability-based decision-making software for MMSs that can account for the increased uncertainty while retaining overall grid reliability and market stability.

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Analytical model - modeling capability analyzing how an energy storage impact BPA balancing reserves and current power & transmission system	ARPA-E University of Washington	**NO**	**Energy Positioning: Control and Economics** The University of Washington will develop control technologies for energy management. The technology will intelligently decide if excess energy from renewable energy sources should be consumed or directed to storage facilities. If directed to a storage facility, the control technology will also decide to route the energy to a location that is best positioned for later use. The coordinated control of well-positioned and properly sized storage facilities and demand response will facilitate the large-scale integration of renewable generation, significantly reduce the need for transmission expansion, and improve system reliability.
Variable generation increases wear & tear due to increase operations of power control breakers to switch caps for voltage control	ARPA-E Michigan State University	**NO**	**Transformer-less Unified Power Flow Controller for Wind and Solar Power Transmission** Michigan State will develop a unified power flow controller (UPFC) that will have enormous technological and economic impacts on controlling the routing of energy through existing power lines. The UPFC will incorporate an innovative circuitry configuration that eliminates the transformer, an extremely large and heavy component, from the system. As a result, it will be light weight, efficient, reliable, low cost, and well suited for fast and distributed power flow control of wind and solar power.
Variable generation also changes path flows impacting voltage, voltage stability and system oscillation	BPA PL: Dmitry Kosterev	**YES**	**TIP 51 - Response Based Voltage Stability Controls** This project researches all three types of controls (primary, secondary, emergency) will be considered. Primary Voltage control - Response-based controls for fast reactive switching of 500-kV shunt capacitor banks in Portland / Salem area. Coordination reactive resources in Southern Oregon / Northern California area. Secondary Voltage Controls - Reactive power management to optimize voltage profile and to maximize reactive margins. Emergency voltage controls - Low voltage shedding. Key Results/Conclusions: ▪ A combination of model-based stability assessment, measurement based tools and response-based Remedial Action Scheme (RAS) are needed to address voltage stability limits. ▪ Operational tools: Several measurement-based tools have been researched and are currently in the prototype phase. ▪ Response-based RAS: Wide-area control system is under the development. WACS will be deployed under the synchro-phasor capital program. California-Oregon Intertie reactive coordination studies are in progress. ▪ Wind power plant voltage controls: Voltage control requirements are developed. Secondary voltage control studies are planned. ▪ Load-Induced voltage instability: Load models are developed by WECC. BPA did significant amount of equipment testing, model development and data preparation. Studies indicate that the Portland metro may be at risk of voltage instability due to air-conditioner stalling. The project supports the development of regulatory framework which will have huge impact on the capital investment needs. ▪ Analysis tools: Tools for analysis of wind power plant voltage controls. ▪ Time-sequence power flow: Time-sequence powerflow capabilities in Power World and PSLF; also, the time sequence for studying the impact of wind ramp events on system voltage stability.

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Variable generation also changes path flows impacting voltage, voltage stability and system oscillation	PSERC PL: A.P. Sakis Meliopoulos (Georgia Institute of Technology	**NO**	**Low-Frequency Transmission for Wind Farm Power (S-42)** The project's goal is to evaluate alternative transmission systems from remote wind farms to the main grid using low-frequency AC technology. Low frequency means a frequency lower than nominal frequency. To minimize costs cyclo-converter technology will be utilized resulting in systems of 20/16.66 Hz (for 60/50Hz systems respectively). The technical and economic performance of low-frequency AC transmission technology will be compared to HVDC transmission (including HVDC Light) and conventional AC transmission.
Increasing amounts of flexible dispatchable resources are required to integrate them	EPRI	**NO**	**Grid Planning - Program 40 (2011)** Utilities, transmission companies, and ISOs/RTOs need to plan for future demand growth and provide transmission services for changing generation portfolios. The challenge of meeting reliability requirements with the addition of variable generation and allowing demand response as a capacity resource may necessitate transmission planning to reassess planning objectives. Planning for peak load scenarios may not be sufficient. Evaluation of additional scenarios such as low load and shoulder load, as well as intermittent availability of variable resources, may also be required. Variable resources have two other characteristics that need to be addressed in planning: uncertainty, and a regional nature beyond the traditional utility boundaries. A second focus of this program is to identify and develop solutions and decision-support tools for planners to deal with specific technology gaps to improve overall planning activities. Some projects within the Grid Planning program use phasor measurement to verify models—the foundation for all simulation and analysis efforts—and move traditionally offline analysis tasks closer to online real-time analysis.
Increasing amounts of flexible dispatchable resources are required to integrate them	EPRI	**NO**	**Bulk Power System Integration of Variable Generation - Program 173 (2009-2011)** EPRI research and development in the area of bulk power system integration of variable generation and controllable load will produce knowledge and tools that will help system operators and planners: - Understand the impacts of variable generation and controllable load on system reliability - Control variable generation and controllable load to minimize operational risks - Design robust transmission systems to integrate variable generation and controllable load - Develop system and industry standards that ensure efficient and reliable operation. P173.003 Grid Performance and Modeling of Variable Generation and Evolving Power System Resources P173.005 Operator Tools for Scheduling, Reserve Determination, and Frequency Control with Variable Generation P173.006 Advanced Planning Tools to Study the Impact of Variable Generation and Controllable Loads P173.007 Evaluation of Potential Bulk System Reliability Impacts of Distributed Resources and Potential Mitigating Strategies

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Increasing amounts of flexible dispatchable resources are required to integrate renewables.	Georgia Institute of Technology PL: Santiago Grijalva	NO	**1. Ongoing Research** ARPA-E Green Energy Network Integration, major project proposing a control architecture to achieve 40% penetration of renewable energy. Components are the distributed architecture and the autonomous distributed stochastic optimization Multi-factor analysis for wind planning and operations. - There are many factors involved in comprehensive planning. Requires other types of tools including GIS, multi-factor spatial-temporal methods **2. Research Needs** Top down vision and electricity policy for emerging technologies and method
Increase dynamic transfer capability	ARPA-E Smart Wire Grid, Inc	NO	**Distributed Power Flow Control Using Smart Wires for Energy Routing** Over 660,000 miles of transmission line exist within the continental United States with roughly 33% of these lines experiencing significant congestion. This congestion exists while, on average, only 45-60% of the total transmission line capacity is utilized. A team led by startup company Smart Wire Grid will develop a solution for controlling power flow in the transmission grid to better take advantage of the unused capacity. The power controller will be a “smart wire” that incorporates advanced control software, sensors, and communications technologies.
Modeling capability analyzing how an energy storage impact BPA balancing reserves and current power & transmission system	PSERC PL: George Gross (University of Illinois, Urbana)	NO	**Integration of Storage Devices into Power Systems with Renewable Energy Sources (S-40)** The recent advances in the state of the art of storage technology have led to wider deployment of storage technologies. This project will develop models and a simulation methodology for analyzing the effects of storage integration on transmission constrained electricity markets over longer-term periods. Our goal is to assess the use of storage as a system resource that provides the flexibility to mitigate the effects of variable renewable energy sources, improves the overall system reliability, and has the ability to provide energy- and capacity-based ancillary services. The methodology can be implemented into practical tools to quantify the system variable effects
More robust PCB (power circuit breaker)	ARPA-E General Atomics	NO	**Magnetically Pulsed Hybrid Breaker for High-Voltage Direct Current (HVDC) Power Distribution Protection** General Atomics will develop a low loss, high reliability power routing technology that operates about 10 times faster than conventional technology. This technology will be a key enabler of advanced transmission networks, which will play a vital role in linking remotely located renewable energy sources like offshore wind farms and solar energy fields to consumers in urban centers.
Analytical model - modeling capability analyzing how an energy storage impact BPA balancing reserves and current power & transmission system	Battelle BPA PM: Lee Hall	YES	**TIP 35 - PNW Smart Grid Demo** This project expands upon the region’s experience in the 2006 DOE-funded Pacific Northwest GridWise™ Demonstration Project on the Olympic Peninsula, which successfully tested demand response concepts and technologies. BPA’s role is to coordinate with Battelle and participating utilities to develop a smart grid business case based on data from utilities, customers and project vendors to inform a cost benefit analysis. Lead public outreach and communication with governments (states, Northwest delegation, Tribes, others), non-partner utilities, educational institutions, energy and regulatory organizations (WECC, NERC, NWPCC, NWPPA, etc.), the general public and other regional demonstration projects.

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Provisioning sufficient balancing reserves through the FCRPS or developing other types of reserves than those currently available	Powin Energy BPA PM: Jason Gates 2012 - 2014	**YES**	**TIP 260 - A Modular and Dispatchable Battery Storage System** The proposed project is to deploy, test, and evaluate a scalable, modular, dispatchable battery storage system in real-world trials over a two-year period, first at the BPA testing facility in Vancouver, Washington, and then in BPA's service area of the Pacific Northwest at different utility customer locations. Energy Northwest already wants to host the storage system at its Nine Canyon Wind Project facility, and it has interest from some of its member utilities to host the system at their facilities, who want to get hands-on experience regarding the deployment, integration, operation, and maintenance of a battery storage system for demand response applications. PNNL wants to host the storage system at its facilities too. Deliverables: Phase test and evaluation report ▪ Phase 1: Qualification Testing at BPA's Vancouver Test Facility ▪ Phase 2: Testing at Energy Northwest's Nine canyon wind Facility ▪ Phase 3: Testing at a Utility Facility in the BPA Service Area of the Pacific Northwest ▪ Phase 4: Testing at a PNNL Facility
Provisioning sufficient balancing reserves through the FCRPS or developing other types of reserves than those currently available	EWEB BPA PM: Kari Nordquist 2012 - 2014	**YES**	**TIP 266 - EWEB / Metropolitan Wastewater Management Commission (MWMC)** The goal of the DR Demonstration Project is to demonstrate that the Metro Wastewater facility can act as a dispatchable large utility-scale DR resource (>1MW) to both increase load (DECs) when there is extra capacity on the grid, and decrease load (INCs) during peak periods, capacity constraints, grid emergencies or during periods when renewable resources experience intermittency. M&V of DR events will provide a performance based approach in developing reliable resources that can be used year-round for ancillary services. Deliverables: ▪ Visual analytical methods for data identification and representation. ▪ Methods for identifying operator actions; report to summarize the visual analytical methods and operator action methods for stage gate review. ▪ Training tools and metrics; training session conducted in combination at BPA if BPA can accommodate. ▪ Report on the feasibility of integrating the GCA techniques into operating environment; final project report for stage gate review.

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Provisioning sufficient balancing reserves through the FCRPS or developing other types of reserves than those currently available	City of Port Angeles BPA PM: Tom Brim 2012 - 2014	**YES**	**TIP 270 - Demand Response Demonstration Market** The City of Port Angeles will work with BPA to create and analyze an internal and external demonstration market for INCs and DECs at the commercial and industrial customer locations. The goal is to move the individual technical DR pilot projects further towards a realistic DR market by working out many of the practical issues. The City proposes to develop the demonstration market at two (2) customers' locations with the following load characteristics Deliverables: ▪ The City will provide the overall coordination of the demonstration market. ▪ The City will work with the two commercial and industrial customers to develop a menu of times and their INC or DEC capabilities. Next, the City will work with the BPA and the two commercial and industrial customers to set a price for each of the possible transactions in the different periods. ▪ In order to achieve 15-MW INC or DEC, the Nippon plant will need to change operational conditions of the refiner lines, which are the major loads in the pulping plant. ▪ The Landing Mall has installed a Catalyst Energy Technologies (CET) intelligent energy storage package referred to as Smart Storage Kit™ (SSK). ▪ The City's Morse Creek hydro facility (475-kW) could be available for dispatch by BPA given short ▪ notice or 24 hours notice by the City. ▪ Load profile data for the two main refiner lines at Nippon is currently collected by Nippon's Plant Information (PI) system and is currently sent to a dedicated UISOL's DRBizNet© server. The load profile data used at DRBizNet provides robust load reduction metering data. ▪ Regardless of project outcome, the City has proven to be a willing partner with the BPA in transferring the "lessons-learned" from its DR experiences throughout the region with other BPA customers and those having an interest in DR.
Provisioning sufficient balancing reserves through the FCRPS or developing other types of reserves than those currently available	Ecofys US BPA PM: Jason Gates 2012 - 2014	**YES**	**TIP 277 - Data Centers as Demand Response Resources** This project rapidly develops and deploys technologies and strategies for dynamically managed, distributed data center loads to provide peak shifting, balancing reserves (decreasing and increasing load), transmission investment deferral, and/or transmission congestion management to the BPA balancing area in an economic manner. Deliverables: ▪ Solicitation Document for Use in acquiring bids from technology vendors ▪ Presentation to BPA T/I Staff and other stakeholders at BPA office in Portland. ▪ Interim report outlining the installation experience as well as initial analysis of the proof-of-concept results. ▪ Report outlining the performance of the pilot project over the testing phase. ▪ Final report outlining the demonstration project and future opportunities / challenges. Presentation to BPA staff and other stakeholders at the BPA office in Portland.

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Provisioning sufficient balancing reserves through the FCRPS or developing other types of reserves than those currently available	Primus Power BPA PM: Jason Gates 2012 - 2015	**YES**	**TIP 285 - Energy Storage: Multifaceted tool for demand management** Primus Power EnergyPodsTMare being developed with these uses as their basis. They will work to improve the economics, emissions, efficiency and quality of the entire electrical power delivery system. The EnergyPod is a 250kW – 750 kWh zinc-based flow battery. The objectives will be to Analyze value of distributed storage in Puget Sound Energy's (PSE) distribution system to PSE and BPA, Select a location for a pilot to capture as many different value streams as possible, Develop a control strategy that maximizes the total value of the storage both from a distribution system and transmission perspective, Demonstrate a 500kW, 1 MWh system, analyze the operation, test control algorithms and validate performance and effectiveness. Deliverables: ▪ Assessment of Value of Near-Customer Energy Storage: Primus 3rd Party EnergyCell testing report ▪ Implementation of storage system: Factory and site acceptance protocols ▪ Operational optimization and evaluation of performance: Final report
Provisioning sufficient balancing reserves through the FCRPS or developing other types of reserves than those currently available	CUNY Energy Institute, City College of New York BPA PM: Tom Brim 2012 - 2014	**YES**	**TIP 286 - Energy Storage as a Demand Response Asset at Industrial Facilities and at Critical Points on the Transmission Network to Increase and Decrease Load on Demand** This proposal aims to demonstrate how energy storage can be used at various points on the transmission and distribution network to the benefit of BPA and large consumers of electricity.Questions remain on whether it is more cost-effective for transmission operators to install large energy storage units on the transmission network and pass the cost to all rate payers, or install energy storage at the customer location and share portion of the costs and benefits with customers at the edge of the grid. This study will allow BPA to establish the proper mix of allocation of energy storage between critical congestion points on the transmission network and selected large industrial customers along the distribution network. Deliverables: At the end of the project the recipient will deliver to BPA the following information: ▪ Detailed report on the cost and performances of energy storage at various point on the transmission network maintained by BPA ▪ Compiled Matlab Simulink modules to use in other simulations that BPA would like to run in the future ▪ Complete specification of the energy storage demo if built ▪ Access to real time data of the performance of the demo At the end of the project the recipient will deliver to the NWFPA demo location (if a demo is built) ▪ Control over the energy storage solution ▪ Compiled version of the software to operate the energy storage solution correctly

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Insufficient balancing reserves due to wind generation, increased wear & tear due to increase operations of power control breakers, and changes to path flows impacting voltage, voltage stability and system oscillation.	BPA PM: Kathy DeBoer 2012 - 2015	**YES**	**TIP 281 - Impacts Due to Dynamic Transfers** BPA's plays a vital role in wind power development in the Pacific Northwest. Dynamic Transfer is essential to reliably integrate wind, smart grid and other devices that increase variability. RD 237 developed Dynamic Transfer algorithm. This research will identify 1. The factors that influence the Dynamic Transfers, 2. Identify allowable voltage variation in the transmission system, 3. Approach to minimize labor intensive Dynamic Transfer studies and, 4. Understand Dynamic Transfer limits change with respect to system operating conditions. Deliverables: ▪ Identify possible factors that influence Dynamic Transfer Limits. ▪ Identify the transmission distribution voltage amplification to set voltage variation limits for Dynamic Transfer limit calculation. ▪ Software tool set developed in phase 3, with documentation describing methodology, software implementation, and user guide suitable for technical operations study staff. ▪ Example Plot of Dynamic Transfer limits for a source and for a sink transfer with respect to time calculated using the tool set developed in phase 3. ▪ Final report.
Analytical model - modeling capability analyzing how an energy storage impact BPA balancing reserves and current power & transmission system	PSERC	**NO**	**Coordinated Aggregation of Distributed Demand-Side Resources (S-52)** This research proposes a new architecture to enable deep penetration of variable renewable generation through coordinated aggregation of a diverse collection of distribution-side networked resources [micro-generation, storage, and responsive loads]. We will design coordination strategies, analyze their benefit, and simulate their performance. Our objectives are to demonstrate systemic value in managing resource clusters, and to understand mechanisms to monetize this value.
Changes to path flows impacting voltage, voltage stability and system oscillation	PSERC	**NO**	**Tools and Techniques for Considering Transmission Corridor Options to Accommodate Large Scale Renewable Energy Resources (S-41)** The project develops assessment tools and techniques for considering transmission corridor options to accommodate high levels of penetration of renewable energy resources.
Provisioning sufficient balancing reserves through the FCRPS or developing other types of reserves than those currently available	ARPA-E AutoGrid Systems, Inc.	**NO**	**Highly Dispatchable and Distributed Demand Response for the Integration of Distributed Generation** AutoGrid, in conjunction with Lawrence Berkeley National Laboratory and Columbia University, will design and demonstrate automated control software that helps manage real-time demand for energy across the electric grid. Known as the Demand Response Optimization and Management System - Real-Time (DROMS-RT), the software will enable personalized price signals to be sent to millions of customers in extremely short timeframes—incentivizing them to alter their electricity use in response to grid conditions. This will help grid operators better manage unpredictable demand and supply fluctuations in short time-scales—making the power generation process more efficient and cost effective for both suppliers and consumers. DROMS-RT is expected to provide a 90% reduction in the cost of operating demand response and dynamic pricing programs in the U.S.

Wind Modeling Roadmap

Business and Technology Challenges

The current models of transmission system planning do not effectively incorporate impact of wind generations. Improved modeling of wind resources on the transmission system is needed to provide accurate, real-time information for energy markets, scheduling, reserves management and voltage support. Within hour/next hour reserve management of wind resources and inadvertent interchange with Pacific NW and California load areas needs to be modeled appropriately. Short term wind forecast improvement is needed to accurately forecast reserve requirements and congestion to optimally manage reserves of the Big 10 Columbia/Snake River Dams in real time (Big 10). Balancing authorities cannot control power flows (ex. large solar intermittency in CA demands reserves from Pacific NW on an unscheduled basis). Inadvertent interchange consumes some transmission capacity.

More specific operational challenges are:

- Within Hour/Next Hour Reserve Management of Wind (Schedule Error): Short term wind forecast improvement is needed to accurately forecast reserve requirements and congestion to optimally distribute reserves to the Big 10 in real time.
- Inadvertent Interchange with PNW and California Load Areas: Balancing Authorities can't control power flows (ex. Large solar intermittency in CA demands reserves from PNW on an unscheduled basis). Inadvertent Interchange consumes some transmission capacity.

These challenges require following addition capabilities:

- Power plant model validation
- Improved system modeling and data sharing (data management)
- Understanding characteristics of wind generators

These remedies will give BPA an appropriate wind and solar monitoring system which demonstrates accurate performance expectations from 0 to 60 min.

R&D Gaps

Business and Technological Challenges which are not addressed by existing R&D programs:

1. Power plant model validation
2. Improved system modeling and data sharing (data management)

Business and Technological Challenges which are covered partially by existing R&D programs but still require further research and development:

1. Within Hour/Next Hour Reserve Management of Wind
2. Inadvertent Interchange with PNW and California Load Areas
3. Understanding of the wind generator characteristics

Business and Technological Challenges which are covered by commercialized technologies and products, however demonstration or confirmation studies may be required:

- None

VI-2. Wind Modeling Technology Roadmap

Time: 2012 – 2015

Business Challenges (BC)

BC1 Wind Modeling
The current wind models causes problems with system planning. Improved modeling of wind resources on the transmission system is needed to provide accurate, real-time information for energy markets, scheduling, reserves management and voltage support. (S/M/L)

Operational Challenges (OC)

OC1 Within Hour/Next Hour Reserve Management of Wind (Schedule Error)
Short term wind forecast improvement needed to accurately forecast reserve requirements and congestion to optimally distribute reserves to the Big 10 real time. (S)

OC2 Inadvertent Interchange with PNW and California Load Areas
Balancing Authorities can't control power flows (ex. Large solar intermittency in CA demands reserves from PNW on an unscheduled basis). Inadvertent Interchange Consumes some transmission capacity (S)

Operational & Technical Needs (ND)

ND1 Power Plant Model Validation
Need baseline performance model for all generation resources. (S)

ND2 Improved system modeling data and data sharing (Data Management)
A large number of wind plants are connected, but getting the best model for the plants could be improved. (S)

ND3 Tools to Study Wind Ramps

ND4 Understand wind power which is a different type of generator
What are the different reactive and frequency support characteristics, reserve demands, performance with other generators in a disturbance. [Reliability]

Required Capabilities (RC)

RC1 Wind & Solar Monitoring
Accurate performance expectations from 0 to 60 min

Technologies (T)

T1 Wind and Solar Models
Obtain model structure using accurate generator performance data and automate model validation.

R&D Programs (RD)

University of Illinois (Overbye): Recent project for BPA on enhancing dynamic models for wind.

Legend: Business Challenge | Operational Challenge | Operational & Technical Need | Required Capability | Technologies | Existing R&D Programs | Non-Existing R&D Programs (Gaps)

Related Internal and External Projects

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Improved modeling of wind resources on the transmission system is needed to provide accurate, real-time information for energy markets, scheduling, reserves management and voltage support	University of Illinois (Dr. Thomas Overbye)	**NO**	**1. Ongoing Research** Recent project for BPA on enhancing dynamic models for wind. **2. Research Needs** Sensitivity of operationa, planning and market outcomes on model accuracy. - Model Validation Methods - Modeling/Simulation compliance and certification methods

Wind Power Plant Controls Roadmap

Business and Technology Challenges

Operating the system in stressed conditions increases the probability of severe contingencies or chains of contingencies that are not considered in traditional system security assessment. The scale of wind power developments demands that wind generation facilities be able to exert effective control capability in response to grid requirements such as primary speed-power control, primary voltage control, secondary voltage control and reactive power management. In addition to, communication is another business challenge in wind power plant control. This requires a mechanism for communicating quick reaction commands enabled by new data sets provided by PMUs.

Operational challenges in wind power plant control include:

- System voltage / reactive reserve changes due to fast wind ramps. Conventional methodologies and study tools may not be sufficient or fast enough to accurately initiate the type of reactive control currently deployed or may require accurate system models to be effective.
- Oscillation frequency is drifting lower due to greater inertia on the system.
- PMU data cannot be fully used because State estimator runs once per minute.
- Insufficient reactive control: Conventional methodologies and study tools may not be sufficient or fast enough to accurately initiate the type of reactive control currently deployed or may require accurate system models to be effective.
- Reactive power assignment: Enable stable and equitable reactive power assignment across multiple plants in a hub
- Sub-synchronous frequency control interaction and resonance: Understand risk of sub-synchronous control interactions and oscillation resonance
- Spinning & operating reserves: Balancing Authority ancillary services obligations for wind generators are being filled by other generators on the system.
- Stressed system: Operating the system in stressed conditions increases the probability of severe contingencies or chains of contingencies that are not considered in traditional system security assessment.
- Track Wind Performance for Voltage Control

R&D Gaps

Business and Technological Challenges which are not addressed by existing R&D programs:

1. Voltage control requirements, lessons learned, best business practices
2. Active Power / Frequency Control
3. Wind Power Plant (WPP) to have speed governors

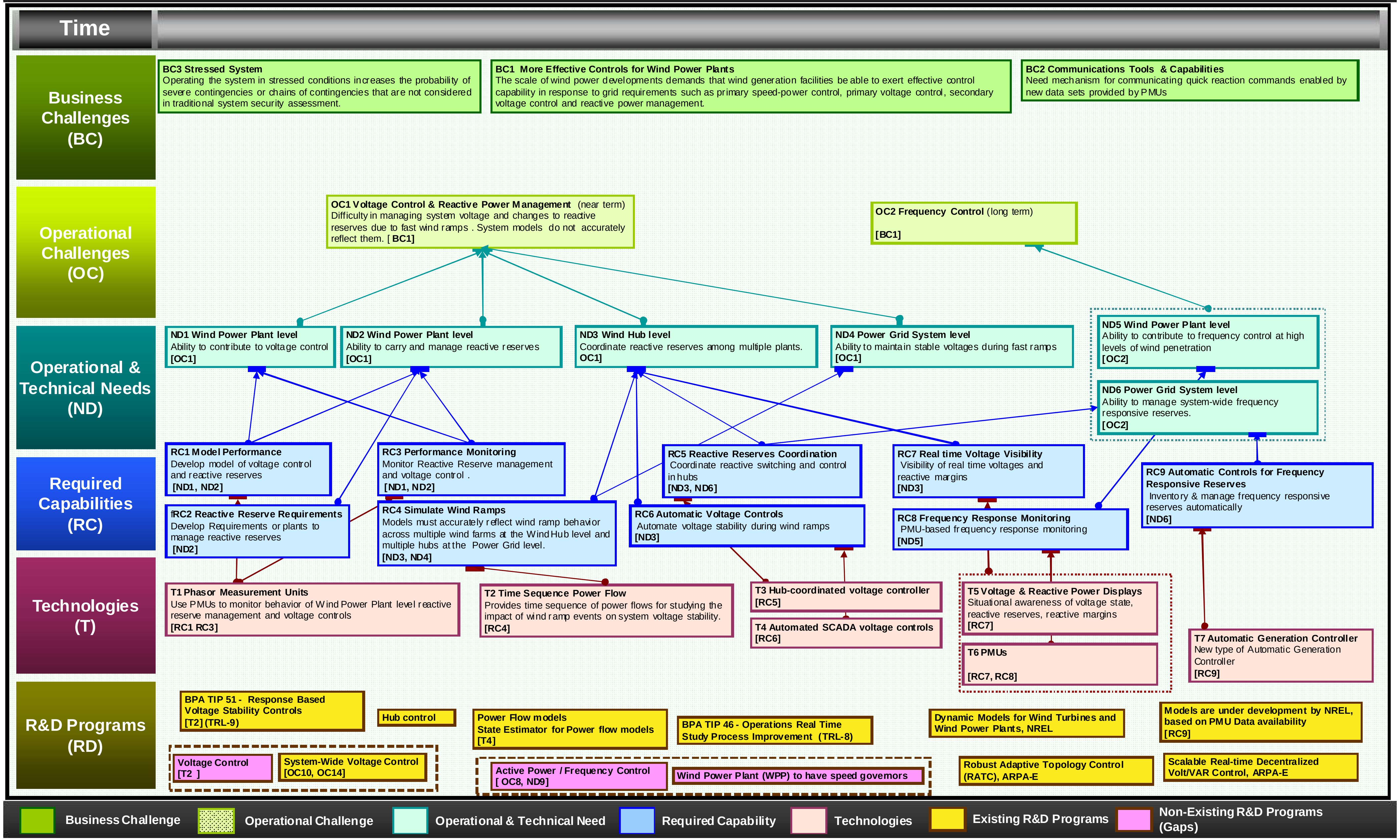
Business and Technological Challenges which are covered partially by existing R&D programs but still require further research and development:

1. Software Applications
   - Software applications that can process PMU data and display results of oscillation detection.
2. Software to monitor for wind power plants performance (PI, enhancement tailoring, expand use needed)
3. Model validation applications using PMU/DFR data (NREL/DOE/UWIC)
4. System-Wide Voltage Control
5. Time sequence power flow

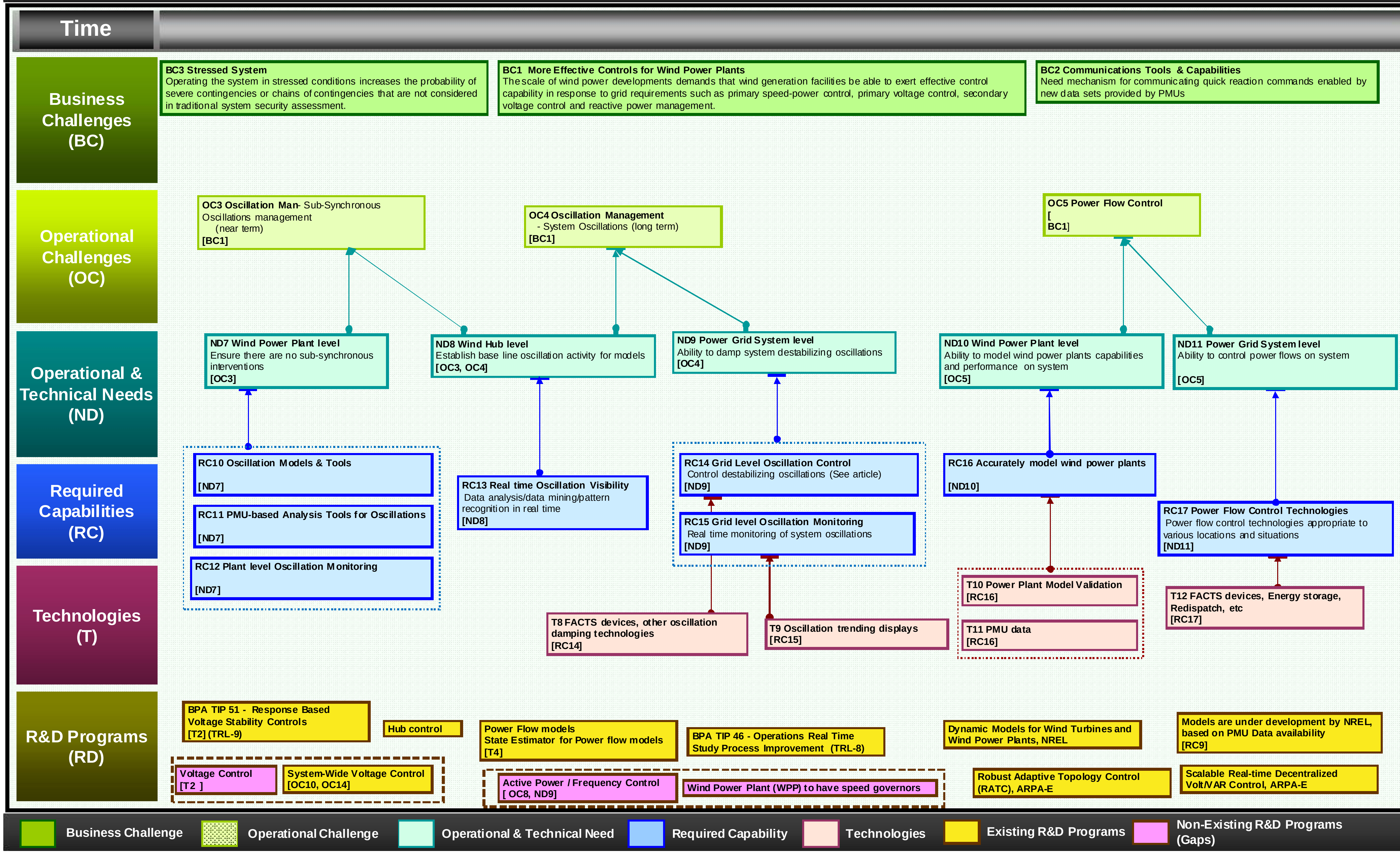
Business and Technological Challenges which are covered by commercialized technologies and products, however demonstration or confirmation studies may be required:

1. Dynamic Power Flow models

VI-3. Wind Power Plant Controls Technology Roadmap – 1/2



VI-3. Wind Power Plant Controls Technology Roadmap – 2/2



Related Internal and External Projects

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
The scale of wind power developments demands that wind generation facilities be able to exert effective control capability in response to grid requirements such as primary speed-power control, primary voltage control, secondary voltage control and reactive power management.	BPA PL: Dmitry Kosterev	**YES**	**TIP 51 - Response Based Voltage Stability Controls** This project researches all three types of controls (primary, secondary, emergency) will be considered. Primary Voltage control – Response-based controls for fast reactive switching of 500-kV shunt capacitor banks in Portland / Salem area. Coordination reactive resources in Southern Oregon / Northern California area. Secondary Voltage Controls – Reactive power management to optimize voltage profile and to maximize reactive margins. Emergency voltage controls – Low voltage shedding. Key Results/Conclusions: ▪ A combination of model-based stability assessment, measurement based tools and response-based Remedial Action Scheme (RAS) are needed to address voltage stability limits. ▪ Operational tools: Several measurement-based tools have been researched and are currently in the prototype phase. ▪ Response-based RAS: Wide-area control system is under the development. WACS will be deployed under the synchro-phasor capital program. California-Oregon Intertie reactive coordination studies are in progress. ▪ Wind power plant voltage controls: Voltage control requirements are developed. Secondary voltage control studies are planned. ▪ Load-Induced voltage instability: Load models are developed by WECC. BPA did significant amount of equipment testing, model development and data preparation. Studies indicate that the Portland metro may be at risk of voltage instability due to air-conditioner stalling. The project supports the development of regulatory framework which will have huge impact on the capital investment needs. ▪ Analysis tools: Tools for analysis of wind power plant voltage controls. ▪ Time-sequence power flow: Time-sequence powerflow capabilities in Power World and PSLF; also, the time sequence for studying the impact of wind ramp events on system voltage stability.

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
System voltage / reactive reserve changes due to fast wind ramps . Conventional methodologies and study tools may not be sufficient or fast enough to accurately initiate the type of reactive control currently deployed or may require accurate system models to be effective.	BPA PL: Brian Tuck	**YES**	**TIP 46 – Operations Real Time Study Process Improvement** This project uses the innovative operations study process improvement environment to investigate options to reduce unnecessary risks and curtailments by accurately modeling near term system conditions for operations study engineers following an unplanned outage or during extreme operating conditions. The study automation system will be designed to assist BPA Systems Operations engineers to calculate a reliable system Operating Limit (SOL) for real time operation of BPA's critical transmission paths such as the California Oregon Intertie (COI). The system will be built around PowerWorld's Simulator power flow that is used daily for off-line studies. Key Results/Conclusions ▪ Implemented distributed processing to use multiple CPUs to speed up system operating limit studies by up to 1000%. ▪ Improved the software efficiency of the automated system operating limit studies adding an additional 600% speed improvement. ▪ State estimator and custom software automatically generate 100 cases a day. ▪ State estimator based studies use real measurements for more accurate system studies. ▪ Implemented a power circuit breaker oriented power flow model to find hidden problems. ▪ Cost savings during unplanned line outage events impacting the northern intertie path (±$665K) and west of Cascades north path (±$793K).
Proprietary Wind Models Models may not accurately simulate wind conditions.	NREL PI: Surya Santoso (University of Texas Austin) 2008 - 2011	**NO**	**Dynamic Models for Wind Turbines and Wind Power Plants** The primary objective of the work proposed is to develop universal manufacturer-independent wind power plant models that can be shared, used, and improved without any restrictions by project developers, manufacturers, and engineers. Each of these models includes representations of general turbine aerodynamics, the mechanical drive-train, and the electrical characteristics of the generator and converter, as well as the control systems typically used. To determine how realistic model performance is, the performance of one of the models (doubly-fed induction generator model) has been validated using real-world wind power plant data. This work also documents selected applications of these models. http://www.nrel.gov/docs/fy12osti/52780.pdf

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
System voltage / reactive reserve changes due to fast wind ramps. Conventional methodologies and study tools may not be sufficient or fast enough to accurately initiate the type of reactive control currently deployed or may require accurate system models to be effective	ARPA-E California Institute of Technology	**NO**	**Scalable Real-time Decentralized Volt/VAR Control** Caltech is developing a distributed automation system that allows distributed generators—solar panels, wind farms, thermal co-generation systems—to effectively manage their own power. To date, the main stumbling block for distributed automation systems has been the inability to develop software that can handle more than 100,000 distributed generators and be implemented in real time. Caltech's software could allow millions of generators to self-manage through local sensing, computation, and communication. Taken together, localized algorithms can support certain global objectives, such as maintaining the balance of energy supply and demand, regulating voltage and frequency, and minimizing cost. An automated, grid-wide power control system would ease the integration of renewable energy sources like solar power into the grid by quickly transmitting power when it is created, eliminating the energy loss associated with the lack of renewable energy storage capacity of the grid.
Operating the system in stressed conditions increases the probability of severe contingencies or chains of contingencies that are not considered in traditional system security assessment.	ARPA-E Texas Engineering Experiment Station (TEES)	**NO**	**Robust Adaptive Topology Control (RATC)** The RATC research team is using topology control as a mechanism to improve system operations and manage disruptions within the electric grid. The grid is subject to interruption from cascading faults caused by extreme operating conditions, malicious external attacks, and intermittent electricity generation from renewable energy sources. The RATC system is capable of detecting, classifying, and responding to grid disturbances by reconfiguring the grid in order to maintain economically efficient operations while guaranteeing reliability. The RATC system would help prevent future power outages, which account for roughly $80 billion in losses for businesses and consumers each year. Minimizing the time it takes for the grid to respond to expensive interruptions will also make it easier to integrate intermittent renewable energy sources into the grid.

VII. Changing Load Characteristics

End Use (customer/utility) Devices Roadmap

Business and Technology Challenges

Changing characteristics of end-use devices are a critical business challenge for the BPA transmission system.

New products also need to include designs that support grid flexibility. Otherwise, we may face transmission voltage recovery delayed events such as those caused by stalled air-conditioner compressors. Multiple faults induced delayed voltage recovery events occurred in Southern California Edison's desert regions during the peak air-conditioning period including a major incident which affected a 1000 square mile area in Riverside County.

Therefore, BPA needs base-testing for load composition through new lab testing facilities. Grid friendly devices and better load management tools that enhance the transmission system operation will contribute to this area. The facilities are also needed for automatic load control devices.

R&D Gaps

Business and Technological Challenges which may be addressed by ***collaboration*** *with others*

1. Base-testing for load composition through new lab testing facilities

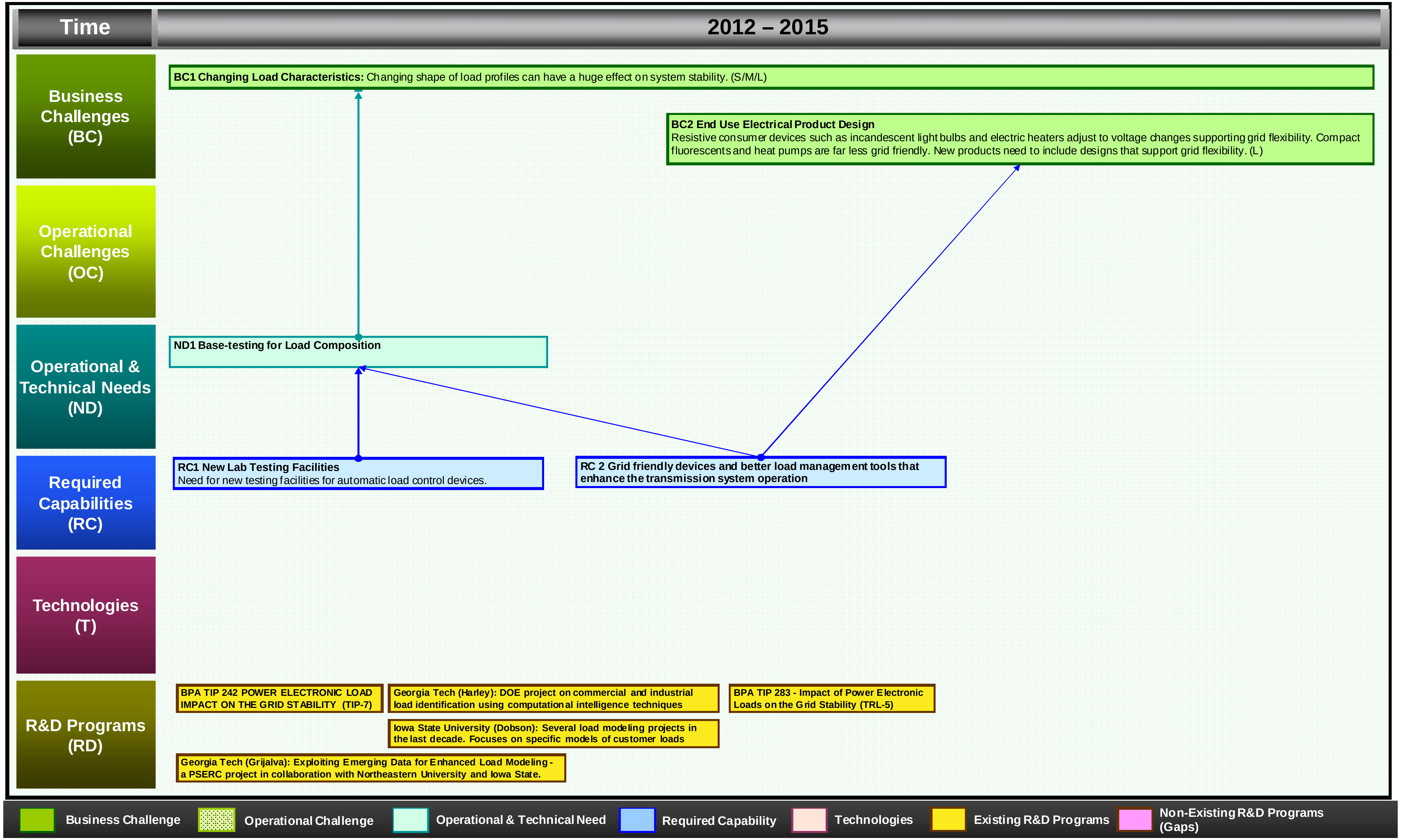
Business and Technological Challenges which are covered partially by existing R&D programs but still require further research and development:

1. New products also need to include designs that support grid flexibility

Business and Technological Challenges which are covered by commercialized technologies and products, however demonstration or confirmation studies may be required:

- None

VII-1. End Use (Customer/Utility) Devices Technology Roadmap



Related Internal and External Projects

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Changing characteristics of end-use device is another critical business challenge for the BPA transmission system.	Iowa State University (Ian Dobson)	**NO**	**1. Ongoing Research** Several load modeling projects in the last decade. Focuses on specific models of customer loads.
Changing characteristics of end-use device is another critical business challenge for the BPA transmission system.	Georgia Institute of Technology (Dr. Santiago Grijalva)	**NO**	**1. Ongoing Research** Exploiting Emerging Data for Enhanced Load Modeling - a PSERC project in collaboration with Northeastern University and Iowa State. - Project includes three levels: a) Dynamic state estimator and dynamic load identification for transmission, b) data mining aspects for demand response using smart meters, and c) non-intrusive dynamic load identification **2. Research Needs** - Data acquisition in the next 2-3 years will 4 orders of magnitude the present volume. There has been little research on "what can be done with the emerging data" (PMU, IEDs, smart meters) - Very limited expertise on databases within the power community and long learning curve for CS community regarding power needs - very limited number of hybrid CS/power researchers - Research on this area is very promising. Several National Labs are interested in partnering in this area.
Changing characteristics of end-use device is another critical business challenge for the BPA transmission system.	Georgia Institute of Technology (Dr. Ronald G. Harley)	**NO**	**1. Ongoing Research** DOE project on commercial and industrial load identification using computational intelligence techniques

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
New products also need to include designs that support grid flexibility. Otherwise, we may face transmission voltage recovery delayed events such as those caused by stalled air-conditioner compressors.	BPA PI: Dmitry Kosterev PM: Steve Yang 2011 - 2015	**YES**	**TIP 242 - Power Electronic Load Impact on the Grid Stability** The project will evaluate the impact of power electronic loads on the power system stability, specifically dynamic voltage stability, damping of power oscillations, frequency controls. The project will look at a wide spectrum of power electronic loads, including Variable Frequency Drives, consumer electronics, LED lighting, and Electric Vehicle Chargers. The project will help simulate, test and evaluate designs that can make these electronic loads be friendly with respect to electrical power grid. The project will provide technical input to a much larger DOE and NERC efforts in addressing the power system stability impact due to increasing penetration of power electronic loads, raising the awareness of the grid effects of electronic loads among the equipment manufacturers, and to support the development of the grid-friendly end-use standards. Deliverables: ▪ System impact study report (Stage Gate 1). ▪ Test reports for power electronic end-uses (Stage Gate 2). ▪ Simulation models of power electronic end-uses and their controls (Stage Gate 3). ▪ Feasibility report of modifying power electronic characteristics. ▪ Report evaluating the applicability of the grid-friendly power electronic devices. ▪ Presentation materials for DOE, NERC and manufacturing organizations
Changing characteristics of end-use device is another critical business challenge for the BPA transmission system.	BPA PM: Steve Yang 2012 - 2016	**YES**	**TIP 283 - Impact of Power Electronic Loads on the Grid Stability** The project will evaluate the impact of power electronic loads on the power system stability, specifically dynamic voltage stability, damping of power oscillations, frequency controls. The project will look at a wide spectrum of power electronic loads, including Variable Frequency Drives in (VFD-driven heat pumps, fans, cooling water circulation pumps, etc), consumer electronics, and Electric Vehicle Chargers. The project will help simulate, test and evaluate designs that can make these electronic loads be friendly with respect to electrical power grid. Deliverables: ▪ System impact study report as described in Task 1 (Stage Gate 1) ▪ Test reports for power electronic end-uses as described in Task 2 (Stage Gate 2) ▪ Simulation models of power electronic end-uses and their controls as described in Task 3 (Stage Gate 3) ▪ Feasibility report of modifying power electronic characteristics ▪ Report evaluating the applicability of the grid-friendly power electronic devices ▪ Presentation materials for DOE, NERC and manufacturing organizations

VIII. Asset Management & Innovation

Equipment Replacement and Upgrade Roadmap

Business and Technology Challenges

BPA's aging infrastructure requires equipment replacement & upgrade projects which are a large investment and present BPA several business challenges and operational challenges. New standards (ISC 6180) are driving major changes in equipments.

Business Challenges:

- Projects should enhance the economic, environmental and operational value of the transmission system in order to support the load growth and marketing needs of our transmission customers
- Increased capacity of the transmission system without large capital investment while, increasing transmission's transfer capabilities
- Preserving transmission capacity inventory while performing maintenance on the grid
- Maximize the value from existing infrastructure
- Operate the power system adequately and reliably with aging assets of the federal power and transmission system in need of substantial maintenance, replacement or upgrades
- Asset management tools and data quality are needed for effective asset management decision plans
- Change practices to leverage new technologies to reduce maintenance e.g. new equipment may require less or no maintenance

Operational Challenges:

- Changing system dynamics due to wind integration affects equipment e.g. some breakers are not adequately sized
- Impact of equipment replacement/upgrades on the system
- Lack of awareness of steel line damage or conditions can result in emergency replacements
- More effective use of software systems (passport cascade limitations and compatibility); data sets for asset management not complete, not automated; All require too much human labor for AM plans and trending performance
- Faster state estimation calculations also require more frequent updates of status of switches and devices in the field.
- T-line replacements of components while the T-line is operational
- Quick assessment filter reduce complexity of roadmap for quick assessment of applications of new innovations, methods, and equipment
- Establish guidelines when to replace/upgrade vs. monitor and/or repair
- Current AM software lacks needed functions and compatibility to produce many automated processes

R&D Gaps

Business and Technological Challenges which are not addressed by existing R&D programs:

1. Transformer life extension
   - Develop methods for transformer life extension
2. Measure (and correct) high temperature transmission SAG, pull out SAG (NOTE “slack sucker” evaluation)

Business and Technological Challenges which are covered partially by existing R&D programs but still require further research and development:

1. Improve technology of barehanded maintenance and live line techniques improvement
2. Work site surge protection
   - Evaluate the use of localized (work site) use of surge arrestors and portable protective gaps
3. Transformer assessment
   - Develop methods for transformer life assessment
4. HVDC Investigate
   - HVDC possibility for existing AC lines
5. New Sensors: New sensors can provide better system and equipment performance.

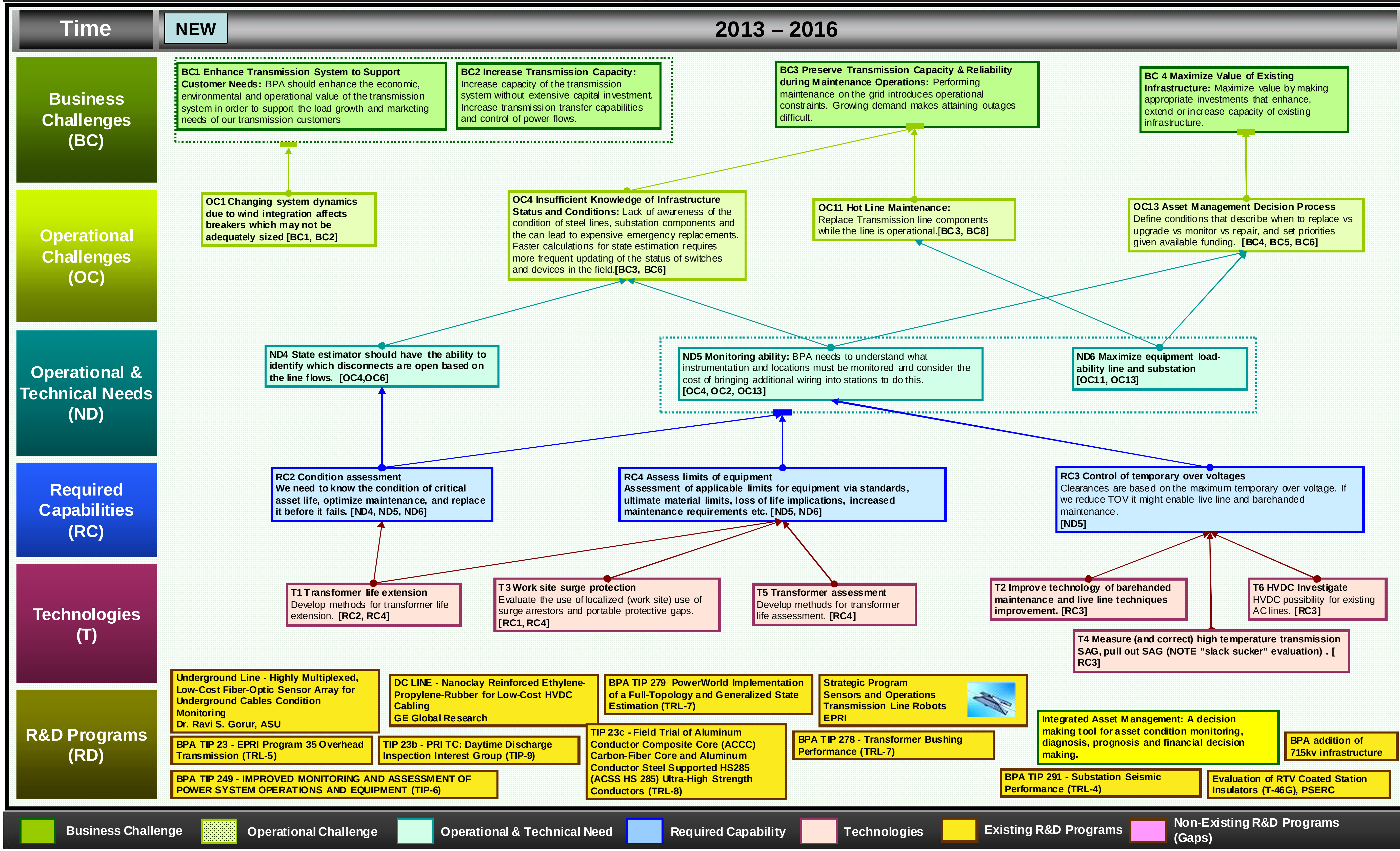
Business and Technological Challenges which are covered by commercialized technologies and products, however demonstration or confirmation studies may be required:

- None

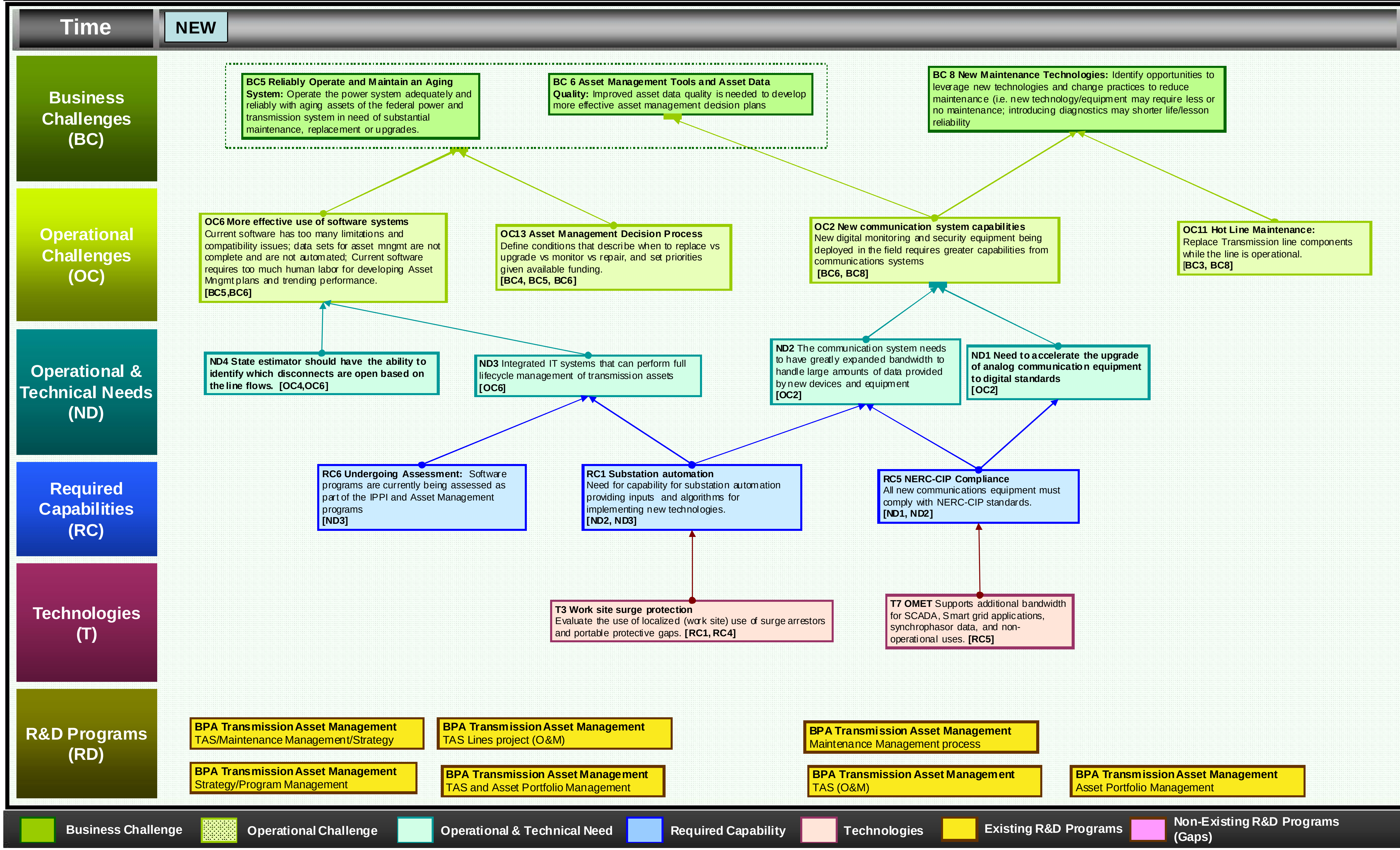
VIII. Asset Management & Innovation

VIII-1. Equipment Replacement & Upgrade Technology Roadmap – 1/2

BPA Transmission Technology Roadmap



VIII-1. Equipment Replacement & Upgrade Technology Roadmap – 2/2



Related Internal and External Projects

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Insufficient knowledge of life expectancy or condition of many substation components Maximize the value from existing infrastructure	EPRI BPA PM: Mike Staats Richard Becke 2012	YES	**TIP 23 - EPRI Program 35 Overhead Transmission** EPRI's Overhead Transmission Program offers a portfolio of products and technologies to cut O&M costs, reduce capital expenditures for new/ refurbished equipment, improve reliability, and improve safety. Projects in the program also address the related areas of extending equipment life, ensuring health and safety for workers, & reducing impacts on the environment. Key Results/Conclusions: • Value assessments of both P35 and P37 programs and TC projects. • Added SME project oversight plans a part of our management of EPRI project involvement. • Trip reports that include assessing current project value and documenting other opportunities. • Added one new TC project to P35. • Added two new TC projects to P37. • Partnering with TI staff in efforts to obtain value metrics from EPRI for its projects and deliverables.
Change practices to leverage new technologies to reduce maintenance e.g. new equipment may require less or no maintenance	EPRI PI: Fabio Bologna BPA PM: Tyler Ashburn 2011	YES	**TIP 23b - PRI TC: Daytime Discharge Inspection Interest Group** The Daytime Discharge Inspection Interest Group was initiated in 2007 to help the industry maximize the use of Daylight UV camera technology for inspection and maintenance of the power network. An ongoing challenge is the improved understanding and diagnosis of the visual images taken from the camera by developing training material and undertaking fundamental research on UV & IR inspection. Key Results/Conclusions: • Researched Inspection of Damaged Porcelain Insulators • Developed Level 1 Inspector Standards Training Material • Updated Field Guide including embedded videos • Educational Slide Show, Meeting/Workshop (Hosted at EPRI's HV Lab in Lenox)
Change practices to leverage new technologies to reduce maintenance e.g. new equipment may require less or no maintenance	EPRI BPA PM: Tyler Ashburn 2012 - 2014	YES	**TIP 23c - Field Trial of Aluminum Conductor Composite Core (ACCC) Carbon-Fiber Core and Aluminum Conductor Steel Supported HS285 (ACSS HS 285) Ultra-High Strength Conductors** This research project seeks to provide information on the operational performance of ACCC (CTC) and ACSS HS285 under extreme electrical and mechanical loading conditions through approximately three years of field experience. The two conductors will be strung for two spans consisting of approximately 780 feet. Each conductor will have two splices installed and two dead-end hardware assemblies. The anticipated benefits of this project include a better understanding of the two subject conductors, as well as more information to use in the evaluation of advantages and disadvantages of using these advanced conductors on BPA's system.

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Insufficient knowledge of life expectancy or condition of many substation components	BPA PM: Leon Kempner 2012-2013	**YES**	**TIP 278 - Transformer Bushing Performance** The purpose of this project is to investigate the failure modes of older transformer bushings and mitigation options for the BPA power grid. Worldwide earthquake performance of older transformer bushings has demonstrated the extreme vulnerability, with many failures and significant loss of transformer capacity. The performance of the BPA power grid is important to maintain a reliable supply of energy. Without a reliable power grid the research performed under the TI Road Map preferential topics would not be accessible. Therefore this research indirectly supports the FY13 TI Road Map preferential topics. Deliverables: The research will use static pull tests on selected surplus bushing to investigate the failure modes and to determine the effectiveness of retainer ring designs. The final retainer ring designs will then be tested in a simulated earthquake using shake table testing. The resulting product will be a retainer ring that can be installed on exiting transformer bushings. ▪ Retainer ring design(s) ▪ Project research reports
Asset management tools and data quality are needed for effective asset management decision plans Establish guidelines when to replace/upgrade vs. monitor and/or repair	BPA PM: Scott Lissit	**YES**	**TIP 249 - Improved Monitoring and Assessment of Power System Operations and Equipment** This project demonstrates a cost effective monitoring solution delivering accurate, reliable information – supporting a wide range of predictive analyses and fault detection – enabling improvements in the data employed for applications from phasor measurement to asset maintenance to providing the information necessary to the effective application of power electronics, helping to improve service delivery, asset longevity and productivity. Using optical sensors developed by the United States Navy and licensed by SSC, the monitoring solution delivers continuous, highly accurate measurements of temperature, pressure, current, voltage and material strain. Deliverables: ▪ Establish viability of equipment/operations in HV Lab, Ross Test Facilities, and if approved at two “linked” substations. Should result in: ▪ Higher levels of accuracy, in actual field operations, than those achieved by other monitoring techniques. ▪ More detailed historic data base, both at point of operations and at central monitoring and control locations. ▪ More detailed real time data. ▪ Long term price/performance advantage. ▪ Demonstration of technological robustness.

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Faster state estimation calculations also require more frequent updates of status of switches and devices in the field.	PowerWorld BPA PM: Gordon Matthews 2012 - 2013	**YES**	**TIP 279 - Implementation of a Full-Topology, Robust, and Generalized State Estimator** The goal of this project is to create a state estimator which overcomes this limitation by meeting two major objectives as follows: 1. Must include integrated topology error detection, 2. Must operate on a single power system model representing the full-topology Deliverables: ▪ A PowerWorld Simulator/Retriever version that includes an orthogonal factorization built on QR factorizations using givens rotations ▪ A PowerWorld Simulator/Retriever version that includes expanded state estimation algorithms to utilize full-topology Models ▪ A PowerWorld Simulator/Retriever version that includes full implementation of topology error detection in the full-topology framework ▪ A final report detailing the completed tasks and the updated software
Insufficient knowledge of life expectancy or condition of many substation components Asset management tools and data quality are needed for effective asset management decision plans	BPA PM: Mike Riley 2012 - 2014	**YES**	**TIP 291 - Substation Seismic Performance** The purpose of this project is to investigate the seismic performance of BPA existing substation designs. This project will analyze typical 115kV, 230kV, and 500kV substation bay configurations. The seismic vulnerability of existing installations will be determined and selected mitigation options will be evaluated. Mitigation options could include new design standards for equipment replacement and/or supplemental damping devices. One damping device that will be included was developed under a separate TI research project. This project is significant for establishing available mitigation options to reduce the seismic vulnerability of BPA's legacy transmission system. Deliverables: The deliverables for this project are substation bay configuration models of three different substations, with a final report, and a full-scale, three-dimensional seismic table verification testing final report.
Change practices to leverage new technologies to reduce maintenance	Dr. Ravi S. Gorur, ASU	**NO**	**Underground Line - Highly Multiplexed, Low-Cost Fiber-Optic Sensor Array for Underground Cables Condition Monitoring** Dr. Gorur of ASU is developing a system to monitor underground cables. Underground cables represent up 20% of distribution lines in the US. These cables do not all age uniformly and unnecessarily replacing cables could waste millions of dollars. This system would help find faults in the cables for selective replacement.
Change practices to leverage new technologies to reduce maintenance	GE Global Research	**NO**	**DC LINE - Nanoclay Reinforced Ethylene-Propylene-Rubber for Low-Cost HVDC Cabling** GE is developing new, low-cost insulation for high-voltage direct current (HVDC) electricity transmission cables. GE is embedding nanomaterials into specialty rubber to create its insulation. Not only are these materials less expensive than those used in conventional HVDC insulation, but also they will help suppress excess charge accumulation.

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Change practices to leverage new technologies to reduce maintenance Preserving transmission capacity inventory while performing maintenance on the grid	EPRI	**NO**	**Sensors and Robots** Equipment is aging and maintenance budgets are shrinking. In response to these challenges, sensors and robots have emerged as key tools in the move to a smarter transmission grid.
Change practices to leverage new technologies to reduce maintenance	PSERC	**NO**	**Evaluation of RTV Coated Station Insulators (T-46G)** Evaluate and quantify the performance of RTV-coated porcelain insulators when compared with uncoated porcelain and composite insulators.

Extreme Event Hardening Roadmap

Business and Technology Challenges

The agency's critical transmission assets, services and functions can be disrupted because of extreme events resulting in regional economic hardship, threats to regional health and safety, and significant restoration costs. BPA is challenged to enhance future grid reliability, interoperability and extreme event protection for increasingly complex system operation. New technologies are expected to enhance resilience of the bulk electric system and physical protection of critical individual assets.

Operational challenge is to prepare systems and operational practices for each extreme event including seismic events, volcano eruptions, extreme weather, forest fires (vegetation management), landslides, sabotage/terrorism, and extreme Geo-magnetically induced current events.

Operational and technical needs are:

- GIC extreme event: there is no valid model for (a) transformer heating/failure, (b) transformer test – Model increased VARS, and (c) relay mal-operation due to harmonics.
- Improve resiliency of power system to seismic events.
- Coordination with transmission operations.
- Transmission structures seismic vulnerability.
- Document historical incidents to define critical measurement and prioritization of enhancements.
- Define critical and non-critical asset.
- Interaction with outside agencies from outside the affected area for communications.
- Develop adequate response plans for extreme events.
- After event monitoring: identify measurements necessary to protect or monitor after extreme event
- Enable people to continue working (or work) after an event. Communication – technical and personal
- Black start: facilitate black starts (first generator to come online after black-out)
- Having timely access to materials and expertise necessary for restoration of the power system.
- Training (drills) for extreme events

R&D Gaps

Business and Technological Challenges which are not addressed by existing R&D programs:

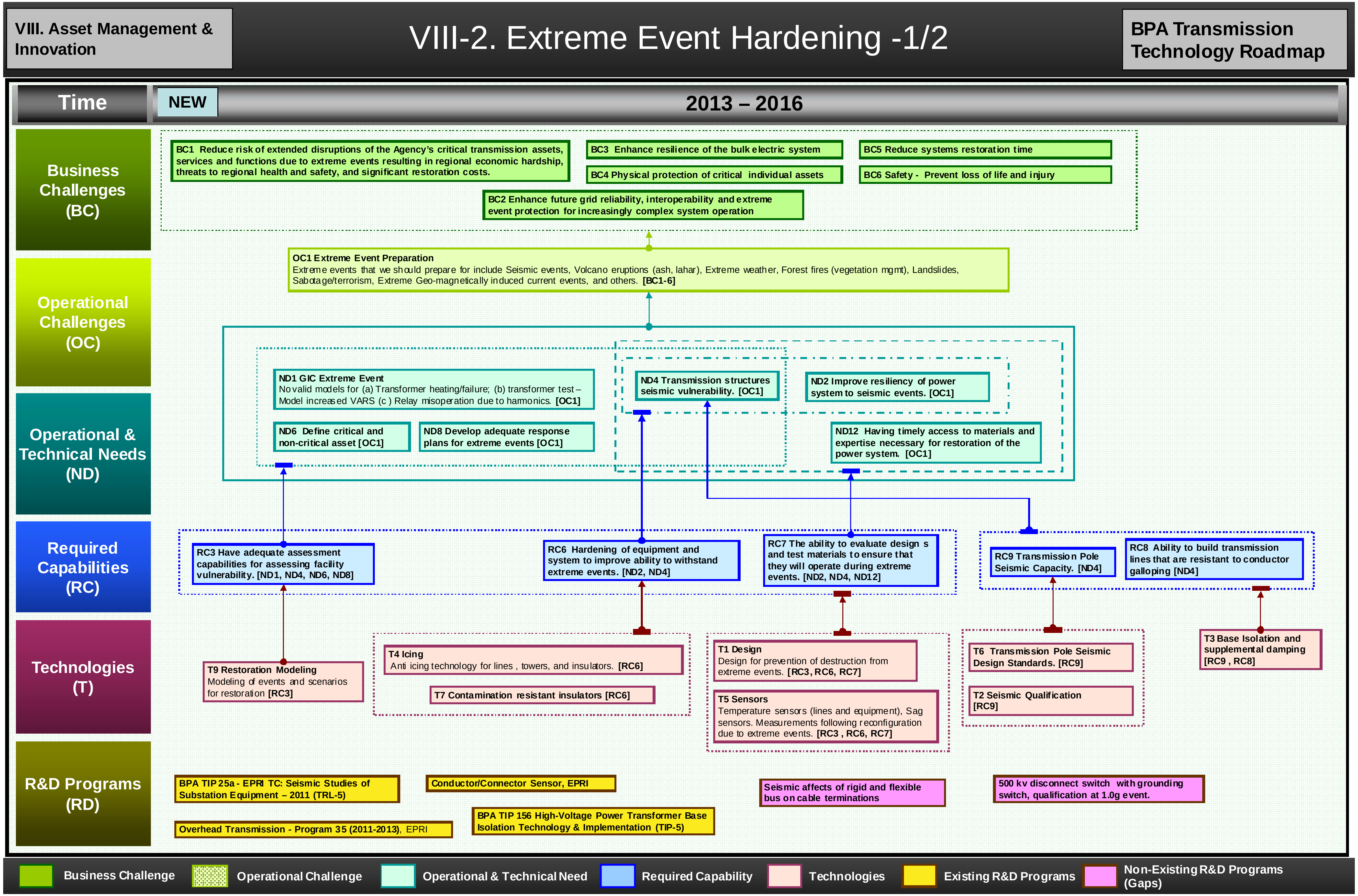
1. Seismic affects of rigid and flexible bus on cable terminations
2. 500 kv disconnect switch with grounding switch, qualification at 1.0g event.

Business and Technological Challenges which are covered partially by existing R&D programs but still require further research and development:

1. Transmission Pole Seismic Design Standards
2. Restoration Modeling
   - Modeling of events and scenarios for restoration
3. Temperature Sensors (lines and equipment) and Sag Sensors
   - Measurements following reconfiguration due to extreme events
4. Improve technology of barehanded maintenance and live line techniques improvement

Business and Technological Challenges which are covered by commercialized technologies and products, however demonstration or confirmation studies may be required:

- None



VIII. Asset Management & Innovation
VIII-2. Extreme Event Hardening -1/2
BPA Transmission Technology Roadmap
Time
NEW
2013 – 2016
Business Challenges (BC)
Operational Challenges (OC)
Operational & Technical Needs (ND)
Required Capabilities (RC)
Technologies (T)
R&D Programs (RD)
BC1 Reduce risk of extended disruptions of the Agency's critical transmission assets, services and functions due to extreme events resulting in regional economic hardship, threats to regional health and safety, and significant restoration costs.
BC3 Enhance resilience of the bulk electric system
BC5 Reduce systems restoration time
BC4 Physical protection of critical individual assets
BC6 Safety - Prevent loss of life and injury
BC2 Enhance future grid reliability, interoperability and extreme event protection for increasingly complex system operation
OC1 Extreme Event Preparation
Extreme events that we should prepare for include Seismic events, Volcano eruptions (ash, lahar), Extreme weather, Forest fires (vegetation mgmt), Landslides, Sabotage/terrorism, Extreme Geo-magnetically induced current events, and others. [BC1-6]
ND1 GIC Extreme Event
No valid models for (a) Transformer heating/failure; (b) transformer test – Model increased VARS (c) Relay misoperation due to harmonics. [OC1]
ND4 Transmission structures seismic vulnerability. [OC1]
ND2 Improve resiliency of power system to seismic events. [OC1]
ND6 Define critical and non-critical asset [OC1]
ND8 Develop adequate response plans for extreme events [OC1]
ND12 Having timely access to materials and expertise necessary for restoration of the power system. [OC1]
RC3 Have adequate assessment capabilities for assessing facility vulnerability. [ND1, ND4, ND6, ND8]
RC6 Hardening of equipment and system to improve ability to withstand extreme events. [ND2, ND4]
RC7 The ability to evaluate design s and test materials to ensure that they will operate during extreme events. [ND2, ND4, ND12]
RC9 Transmission Pole Seismic Capacity. [ND4]
RC8 Ability to build transmission lines that are resistant to conductor galloping [ND4]
T9 Restoration Modeling
Modeling of events and scenarios for restoration [RC3]
T4 Icing
Anti icing technology for lines, towers, and insulators. [RC6]
T7 Contamination resistant insulators [RC6]
T1 Design
Design for prevention of destruction from extreme events. [RC3, RC6, RC7]
T5 Sensors
Temperature sensors (lines and equipment), Sag sensors. Measurements following reconfiguration due to extreme events. [RC3 , RC6, RC7]
T6 Transmission Pole Seismic Design Standards. [RC9]
T2 Seismic Qualification [RC9]
T3 Base Isolation and supplemental damping [RC9 , RC8]
BPA TIP 25a - EPRI TC: Seismic Studies of Substation Equipment – 2011 (TRL-5)
Conductor/Connector Sensor, EPRI
Overhead Transmission - Program 35 (2011-2013), EPRI
BPA TIP 156 High-Voltage Power Transformer Base Isolation Technology & Implementation (TIP-5)
Seismic affects of rigid and flexible bus on cable terminations
500 kv disconnect switch with grounding switch, qualification at 1.0g event.
Business Challenge
Operational Challenge
Operational & Technical Need
Required Capability
Technologies
Existing R&D Programs
Non-Existing R&D Programs (Gaps)

VIII-2. Extreme Event Hardening -2/2

Time NEW

Business Challenges (BC)

- BC1 Reduce risk of extended disruptions of the Agency's critical transmission assets, services and functions due to extreme events resulting in regional economic hardship, threats to regional health and safety, and significant restoration costs.
- BC3 Enhance resilience of the bulk electric system
- BC4 Physical protection of critical individual assets
- BC5 Reduce systems restoration time
- BC6 Safety - Prevent loss of life and injury
- BC2 Enhance future grid reliability, interoperability and extreme event protection for increasingly complex system operation

Operational Challenges (OC)

- **OC1 Extreme Event Preparation**
  Extreme events that we should prepare for include Seismic events, Volcano eruptions (ash, lahar), Extreme weather, Forest fires (vegetation mgmt), Landslides, Sabotage/terrorism, Extreme Geo-magnetically induced current events, and others. **[BC1-6]**

Operational & Technical Needs (ND)

- **ND1 GIC Extreme Event**
  No valid models for (a) Transformer heating/failure; (b) transformer test – Model increased VARS (c) Relay misoperation due to harmonics. [OC1]
- ND3 Coordination with Transmission Operations. [OC1]
- ND7 Interaction with outside agencies from outside the affected area for communications. [OC1]
- ND13 Training (drills) for extreme events. [OC1]
- ND5 Document historical incidents to define critical meas., prioritization of enhancements. [OC1]
- ND6 Define critical and non-critical asset [OC1]
- ND8 Develop adequate response plans for extreme events [OC1]
- ND12 Having timely access to materials and expertise necessary for restoration of the power system. [OC1]
- **ND9 After Event Monitoring**
  Identify measurements necessary to protect or monitor after extreme event. [OC1]
- ND10 Enable people to continue working (or work) after an event. Communication – technical and personal). [OC1]
- **ND11 Black Start**
  Facilitate black starts (First generator to come online after black-out) [OC1]
- ND2 Improve resiliency of power system to seismic events. [OC1]

Required Capabilities (RC)

- RC1 Have appropriate standards for extreme event performance of facilities and equipment [ND5, ND6, ND8, ND9, ND10]
- RC4 Have tools for evaluating benefit of mitigation options [ND8, ND11]
- **RC5 Operational Reaction Capability to Solar Flare Events**
  Capability to protect hardware from solar flares events by taking them off-line. [ND1, ND8, ND12]
- RC2 Have sufficient equipment spares available for extreme events [ND2, ND11]

Technologies (T)

- T8 Restoration design, methods, industry standards [RC1, RC5, RC7]
- T10 Develop Plan for restoration after extreme events [RC1, RC2, RC4]

R&D Programs (RD)

- BPA TIP 25a - EPRI TC: Seismic Studies of Substation Equipment – 2011 (TRL-5)
- Conductor/Connector Sensor, EPRI
- Overhead Transmission - Program 35 (2011-2013), EPRI
- BPA TIP 156 High-Voltage Power Transformer Base Isolation Technology & Implementation (TIP-5)
- Seismic affects of rigid and flexible bus on cable terminations
- 500 kv disconnect switch with grounding switch, qualification at 1.0g event.

Business Challenge | Operational Challenge | Operational & Technical Need | Required Capability | Technologies | Existing R&D Programs | Non-Existing R&D Programs (Gaps)

Related Internal and External Projects

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
Prepare systems and operational practices for each extreme events	MCEER PI: Dr. A. Reinhorn BPA PM: Leon Kempner 2010 - 2012	YES	**TIP 156: High-Voltage Power Transformer Base Isolation Technology & Implementation** This project demonstrated that exiting base isolation technology can be designed to protect high voltage transformers. A simplified design procedure was develop for design of high voltage transmission applications Research results have been shared with the IEEE 693 Seismic Design Standard and presentations made to numerous utilities. Demonstration project has been developed for implementation of a base isolation design on two of BPA's high voltage transformers Key Results/Conclusions: ▪ Implementation of design procedures and tools that enable evaluation and further use of protective technologies ▪ Identify limitations of base isolation systems, which require innovative solutions ▪ Identify utilities to participate in implementing base isolation of transformers and other equipment ▪ Identify equipment and sites; select base isolation solution from the methods researched ▪ Design and implement a protective solution including equipment, connectors to first conductor support, in-situ ▪ Develop plans for instrumentation and monitoring of demonstration installation(s) ▪ Provide guidance to BPA engineers with design or selection of off-the-shelf solutions (instrumentation, protection, and monitoring) ▪ Provide guidance for monitoring and processing of demonstration installation(s)
Prepare systems and operational practices for each extreme events Improve resiliency of power system to seismic events	EPRI PI: Dr. Ashel Schiff BPA PM: Leon Kempner Jr. 2009 - 2012	YES	**TIP 25a - EPRI TC: Seismic Studies of Substation Equipment – 2011** EPRI will select the item(s) of equipment that is (are) to be tested for each year. EPRI establishes equipment support structure specifications and vibration test requirements, electrical equipment specifications, and test specifications. EPRI will select a vibration testing facility (and electrical testing laboratory, if required) to perform tests and EPRI draws a contract for laboratory services. The manufacturer and the testing laboratory prepare qualification documentation for the equipment that is qualified following IEEE 693 requirements Key Results/Conclusions: - Acceptance Criteria for Qualifying Hollow-Core Composites - Qualifying Components with Complex Geometry, Non-Linear Response, or Non-Measureable Failure Modes - Sine Beat Test Procedure - Table Impulse to Excite Equipment on Shake Table - New Procedure for Qualifying Transformer-Bushing Systems - Orientation of Equipment Modes of Vibration can cause Under- or Over-Testing - Curve Fitting to estimate Damping and Frequency in the Time Domain

BPA Challenge	Lead Research Organization	BPA Sponsoring	Project Title & Project Description
After event monitoring: identify measurements necessary to protect or monitor after extreme event	EPRI	**NO**	**Conductor/Connector Sensor** This project is developing and demonstrating low-cost RF sensors to assess conductors and compression connectors on overhead transmission lines. The sensors measure the following parameters: Temperature, Current, Three axes of inclination, Vibration in three axes (see the project summary for the Vibration Sensor Suite)